NUCLEAR ENGINEERING VOL. 5 NO. 50 JULY, 1960

On Second Thoughts . . .

IT was a rare event at one time for international conferences, concerned with the development of nuclear reactors for power generation, not to be overshadowed and distorted by the dictates of salesmanship or national prestige. The over-optimism that this atmosphere engendered was inevitably followed by a period of pessimism and gloom. In Madrid at the Sectional Meeting of the World Power Conference there was little propaganda but a great deal of honest evaluation of the situation as it stands today. Similarly, at Bournemouth, the British Electrical Power Convention was introduced by an analytical assessment of the problems facing industry and the pressure tactics at times adopted by the large groups were not in evidence. It would appear that nuclear energy has now grown up and whilst conservatism in the assessment of costs and potentials is still the key-note this stems now from a policy of caution rather than one of despair.

In Madrid, quite apart from reports of technical experiences, there has been a restating of truths, not new but none the less refreshing to hear. The most oft-repeated comments concerned the individual aspects of a given installation. Apart from certain broad principles arising from now well-known criteria each new demand for power must be evaluated on its own merits. Not only do the conditions prevailing in one country not necessarily apply to any other but there are sharp variations from area to area within national boundaries. With a country as vast as India, for example, this should scarcely need mention (although it has often been glossed over in the past) but even in the United Kingdom with its compact population and the largest integrated grid network in the world (26,000 MW) costs vary a great deal. Furthermore, the anticipation of demands and the forecasting of cost trends can never be an exact science. This is not to suggest that calculation should be dispensed with but rather that a decision on an individual plant must be taken, to a marked extent, on an *ad hoc* basis.

It is impossible, therefore, to discuss the cross-over when nuclear generation becomes competitive with conventional without this being firmly related to the site in question. In the U.S.A. where fuel costs vary less than in many countries it now seems reasonably certain that in the 35C/10^6B.t.u. fuel costs areas, nuclear plant contracted for in 1968 would be competitive in installations of greater than 300 MW, whereas in the U.K. plant commissioned in 1967 would be competitive, but only provided the demand is there, the site right and existing investment conditions remain the same. This projection must still include assumptions about burn-up and load factor. Evidence is mounting to support the burn-up figures currently adopted and it is noticeable that the U.S. and the U.K. with many hundred MW-years operational experience behind them are much more confident of both availability and utilization being high than those organizations with only secondhand information. France is in the mid-position of having encountered greater difficulties in prototype development.

Whilst then the particular economics of a given plant are of outstanding importance they may still not be overriding. Consideration must be given to the gaining of experience by both utilities and industry, to the availability of nuclear fuel and foreign capital and the existence of adequate ancillary installations for fuel handling and reprocessing. Without some economic disadvantage at the outset or, to put it more practically, without some investment in experience, it will be impracticable to evolve a nuclear programme to the point where nuclear generation can take its proper place in a mixed fuel economy. If the initial start is delayed too long then more serious economic disadvantages will arise in later years. Whether the cross-over point in a given area is in the 'sixties, 'seventies or even 'eighties, few will deny that it will come within a period that must be under consideration if not now, at least soon. The initiation of the programme and the rate of development will be peculiar to the area in question, and these early stages may well see the introduction of techniques which have a transitory life only. A case in point is the addition of fossil-fired superheat to low temperature nuclear stations. In the U.K. this cannot be justified because the first phase is over and the decision to build future nuclear stations will be based on the relative economics prevailing, and those established will be on sites where fossil fuel costs are high.

Countries with a less urgent need for power will in large measure be able to draw upon the advanced knowledge of those with large development and building programmes but it is now generally appreciated that the utilities and the home industries must make this introductory outlay. Of particular importance is this in areas

where foreign capital is really tight and a significant proportion of any new plant must be of native production (as in Spain and Italy).

Of especial significance to them—but also of prime importance to all power utilities—is the availability of nuclear fuels on a commercial basis. Restrictions covering the sale and use of nuclear fuels are proving a great handicap not only on the political level but also to the power station engineer by delaying the introduction of the commercial competition which would allow him to buy in the cheapest market open to him. How long the U.S.A. and the U.K. will continue to apply these offensive regulations concerning inspection is difficult to gauge but there are no signs yet of the relaxation that must eventually occur. In this respect the resentment created in India and the views expressed in Madrid (albeit restrainedly) may help to speed the event. From safety considerations the reprocessing of fuels is likely to remain a Government responsibility for some time to come: this, too, must eventually be placed on a more commercial basis.

The OEEC project, Eurochemic, will enable a start to be made in this direction but a decision to build a European diffusion plant could exert an even greater influence. There would still no doubt have to be restrictions on its sales but inspection by international bodies is one stage less irritating than by single nations.

But to return to Madrid; the reactor designer and manufacturer will not have seen new markets open before him. He will have seen, however, the competitive nature of nuclear generation in the near future and in the appropriate areas he will have been able to discuss with power station engineers costs and programmes on a rational basis. The ultimate markets are undoubtedly large and even the immediate prospects not negligible. There is, unquestionably, a difficult transition period still to circumvent (although as was demonstrated at Bournemouth not worse than that obtaining in the generator field by the move to very large sets) which can cause still further integration of companies. In short the going will be tough but well worth it after all.

Helium Cooling

AT first sight it might appear strange that after promoting the thesis of natural uranium and a common-gas cooling so energetically in the early days Britain should be leading a project based on highly enriched fuel and helium as coolant. Britain's policy towards enriched fuel has been discussed in these pages many times and the HTGC is not so out of line as it allows an approach to the exploitation of the thorium-U^{233} cycle, even if the initial investment must be in U^{235} (as against plutonium) and the total investment in any series of reactors and hold-up in the fuel cycles is, therefore, high. The use of helium has, however, not received much attention in the past and the question must be asked whether, with no indigenous supplies, we can afford to base an advanced reactor system upon this material and whether it will be necessary to evolve from the DRAGON experiment a high temperature system capable of using a more common gas such as nitrogen.

The technical advantages of helium are well known. Being a noble gas the corrosion problems are largely eliminated, although the impurities in the initial charging and the occlusions in the reactor and components may still introduce real compatibility and mass transfer headaches. The coolant circuits remain comparatively inactive (assuming no fuel element breakdown) and the heat transfer characteristics are excellent. From the physics and engineering viewpoints the arguments in favour of helium cooling are strong—even for their medium temperature reactor the U.S. has had little hesitation in adopting it as a coolant.

For the U.S., however, the supply of helium presents no problem; there are vast reserves in the country and transport is straightforward, but for the United Kingdom and many countries abroad the position is very different.

At one time when nearly all countries' atomic energy programmes were formulated with the idea of importing as little as possible from abroad (whether this be as capital or as consumable goods) helium was an objectionable material and should there be only one source of supply probably this attitude would still be dominant. The United States is, however (unlike the case of enriched uranium), not the only source of supply. Canada has large deposits and in Europe too, limited production is available.

From an initial investment point of view there is really no problem. The cost of the helium in the circuit will appear as a capital charge and in normal times there is unlikely to be any difficulty in obtaining supplies. Also there is very little problem in stockpiling a first charge even before a building contract is placed. What is critical is the make up necessary and to a large extent this will depend upon the quality of the design and the quality of the workmanship during construction. Absolute leak-tightness in the system is not possible but it is believed that circuits of the DRAGON type can approach the stage where losses will be negligible. Some make up will, of course, be necessary to account for the helium discharge to atmosphere during charge/discharge operations and the like. The greater problem is the risk of a sudden total loss of coolant necessitating a complete recharging, purging, etc., and an operating organization will not be anxious to keep this quantity of helium in stock, particularly if the reactor is aboard ship. It would appear then that helium will only be a concern from the transport and storage point of view. Should the HTGC prove itself as favourable a system as optimistic estimates of its potential indicate, the necessity for using helium would be a very minor deterrent, and certainly not comparable with the complications of providing highly enriched material up to the time when something approaching a self-sustaining fuel cycle can be established.

DIGEST...

Surveying Significant News

U.K.AEA Licence Agreements with Industry

The first collaboration and licence agreements with industry have been signed by the AEA. Two chemical concerns are to assist in the design and manufacture of radioactive chemical-processing plant. The companies are W. J. Fraser and Nuclear Chemical Plant. Under the agreement the AEA provides in return for royalties: a licence under the AEA's patent cover in the nuclear chemical field; general advice on technical problems; assistance in commissioning and specialized training and further training and information on current work. The agreements cover plant and processes connected with the production of uranium metal billets from uranium ore concentrates and the reprocessing of irradiated fuel elements.

CEGB to Build 400 MW(e) AGR

An AGR, probably of 400 MW(e) capacity is to be built by CEGB for commissioning in or near 1964, Sir Christopher Hinton stated in Madrid. Steam-cooled heavy water moderated reactors or HTGCs could be the succeeding approach to even higher temperatures. Superheat developments in the BWR may lead to a pressure tube system closely analogous to the SCHWR, resulting in the U.S. and U.K. approaches in the long term coming together. The fast reactor should ultimately prove the best burner of near-pure fissile material, but application is liable to be wider in U.S.

Amalgamation of Two Physical Groups

The Institute of Physics and The Physical Society have been amalgamated. The new body is to be called The Institute of Physics and The Physical Society and the first president is Sir John Cockroft with Dr. J. Topping, Dr. W. H. Taylor, Prof. R. W. Ditchburn and Mr. A. J. Philpot as vice-presidents. The qualification for the award of Fellow of The Institute of Physics, Associate of The Institute of Physics and Graduate of The Institute of Physics will remain unchanged and members of the new body holding these diplomas will also be Fellows of The Physical Society.

Second 5-year Plan for JNRI

Leading scientists of the Communist bloc recently met at the eighth session of the scientific council of the Joint Nuclear Research Institute in Dubna near Moscow. Commenting on the second five-year plan for the Institute, the director, Dmitry Blokhintsev, said that it was based on fundamental research into the physics of elementary particles and atomic nuclei with emphasis on the study of the structure of nuclear particles and the exploration of the laws governing births and interaction of these particles. Unexpected results have been achieved in the study of different types of collisions of high-energy particles by means of proton-synchrotrons, showing certain uniformity in neutron behaviour.

Britain's Offer to Euratom

Following talks on possible collaboration between the Inner Six and Outer Seven trade groups, Britain has offered to join Euratom. Mr. John Profumo, Minister of State for Foreign Affairs, has said, that providing she were welcome, Britain would now consider joining the nuclear group of the Inner Six. Euratom have to set up a working committee to study the proposal but it is obvious that certain members of the Euratom Commission view the offer with suspicion.

U.K. Nuclear Power Programme Cut

A Government White Paper on June 20 announced a drastic cut in the U.K. nuclear programme. The Paper is summarized on page 316.

Closing Date for U.K. Ship Reactors

Closing date for the proposals for a reactor for ship propulsion has now been set at July 29 by the Ministry of Transport. Five nuclear power groups are submitting tenders for two types of nuclear reactors suitable for installation in a 65,000-ton oil tanker. The Minister, Mr. Marples, has said that the decision whether to build a tanker and the choice of the actual type of reactor will be made after the tenders have been studied.

German Nuclear Ship Plans

In an effort to get a nuclear ship programme under way West Germany's Federal Government recently announced that it would pay about half the research costs of both a pressurized water and a boiling water project. The Study Society for Nuclear Marine Propulsion have now announced that they will build a new vessel in which it will be possible to test three different types of reactors. This follows the decision not to convert a tanker, *Esso Bolivar*, for nuclear propulsion. A link with Euratom for ship propulsion has also been announced and it has been agreed to set up a working group with the object of obtaining Euratom financial participation.

Exchange of Nuclear Scientists

The first exchange of nuclear scientists between the U.S. and the U.S.S.R. has now taken place. Five U.S. scientists have been to Moscow, visiting high energy physics establishments and five Soviet scientists recently visited controlled thermonuclear research centres in the U.S. The agreement for co-operation in the peaceful uses of nuclear energy was signed in Washington in November, 1959, by Mr. McCone and Prof. V. S. Emelyanov. It provided for the exchange of visits and unclassified technical information in the fields of controlled thermonuclear research; power reactor development; neutron structure and physics and high energy physics.

Indian Power Plant Construction

Following his visit to West Germany, Dr. H. J. Bhabha, chairman of India's Atomic Energy Commission, has said that he would consider offers for sharing in the construction of a nuclear power station by German industry. Dr. Bhabha has also said that it is expected that about 50% of the power station would be built in India. He and other members of the AEC are at present visiting the U.S.S.R. for talks on the possible co-operation in peaceful uses of nuclear energy, including the design and construction of power plants.

Preliminary Studies for Nuclear Superheat

Atomics International are doing a preliminary study of a 300 MW boiling water power plant incorporating nuclear superheat for the U.S. AEC. The study is to serve basically as a survey to assess the potential of zirconium-hydride as a moderator for boiling water steam superheat reactors. The reactor would use slightly enriched uranium as fuel with a water coolant in the boiler and steam coolant in the superheater region. Studies will be made of differences between costs and operating characteristics of the design with a superheat reactor of similar size, moderated entirely by water. Specifications will be drawn up for a prototype 50 MW plant at the same time.

U.K. Isotope Information Centre

The U.K. Atomic Energy Authority have established an isotope information bureau at their H.Q. in Charles II Street, London. Main function of the bureau will be to provide a convenient source of information concerning isotopes and their industrial applications.

Conclusions on Sea Disposal of Nuclear Waste

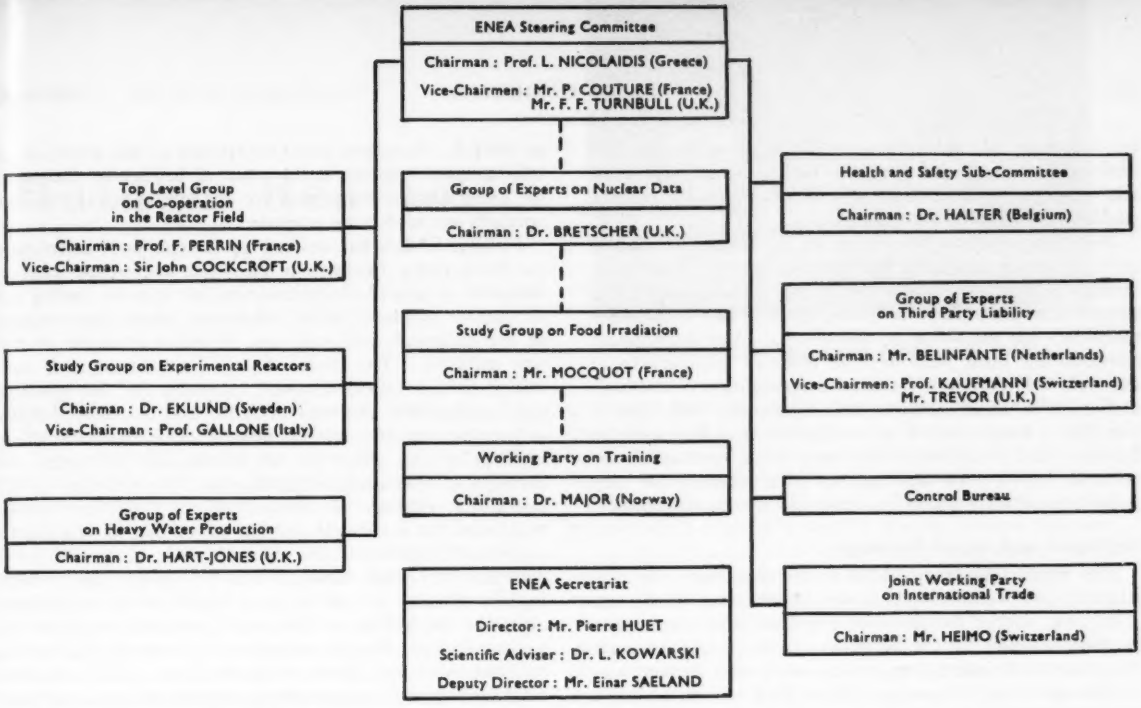
Release of highly radioactive wastes into the sea cannot be recommended as an operational practice according to an international panel of the IAEA. At the same time the panel decided that sea disposals of wastes of low and intermediate activity may be safe under controlled and specified conditions. All radioactive waste disposals into the sea, with the exception of wastes from nuclear powered ships, should be released into designated disposal sites in conformity with conditions specified for the particular site.

Site Work for SENN 150 MW

At last, at long last, G.E.'s 150 MW SENN contract is under way. Site problems and minor political situations have seriously delayed the project until now. G.E.'s APED has designed the dual cycle BWR; some components will be manufactured in San Jose, California, but most will be of Italian make. Ebasco services of New York will supervise station engineering; International General Electric S.A., a Swiss subsidiary of G.E. will be the prime contractor.

U.S. AEC seeks South American Markets

A determined attack on the South American market for nuclear "know-how" is to be made by the U.S. AEC. Spearhead will be a touring exhibition visiting Argentina, Brazil, Peru and Venezuela this year. Main attraction: a low-power pool-type research reactor which is being specially built by Lockheed Aircraft's Georgia nuclear laboratories.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The OEEC European Nuclear Energy Agency

By **PIERRE HUET**
(*Director, ENEA*)

THE countries of Europe concerned with the peaceful uses of atomic energy must take full advantage of the next few years to become more familiar with the operation of the first nuclear power stations, to improve and perfect reactors which have already been tried by experience, to explore the new types which afford promise for the future, and to solve the technical problems raised by the production of the material and equipment needed for the development of the atomic industry. Joint action on a European scale is essential to deal with a range of research and experiment beyond the scope of any single country.

Joint Undertakings

For these reasons the OEEC European Nuclear Energy Agency has concentrated its first major efforts on creating joint undertakings which would enable European countries effectively to pool their efforts in installations jointly constructed or operated. Since ENEA came into being two years ago three joint undertakings have been launched: the first was the Eurochemic Company for the construction (at Mol, Belgium) of a plant for the chemical processing of irradiated fuels; the second for the joint operation of a heavy boiling water reactor built by the Norwegian Institutt for Atomenergi at Halden in Southern Norway, and the most recent, for the joint construction and operation of a high temperature gas-cooled reactor at Winfrith in the United Kingdom and a programme of research and development on this type of reactor (DRAGON project). The majority of European countries are taking part in ENEA's joint undertakings.

These international projects represent a total expenditure approaching $70 million during the next 4 or 5 years, which is a relatively small sum in comparison with the atomic programmes of OEEC countries, which amount to nearly $1,000 million per year. The merit of ENEA's first joint undertakings has been, however, to prove that it takes no longer to agree upon an international project than to obtain approval for a national project. Furthermore, experience during the first months of the lives of the projects indicates that the difficulties inherent in the formation of an international team are more than compensated for by the advantage of being able to draw upon the vaster and more diverse resources offered by a dozen European countries.

Whatever the importance of joint projects, the greater part of scientific and technical effort in the years to come will undoubtedly be on a national basis and it is, therefore, one of ENEA's fundamental tasks to help ensure the best possible use of Europe's resources by discussion of programmes, harmonization of work and exchange of results.

The accurate knowledge of nuclear properties of materials and especially of their behaviour in relation to neutrons and other nuclear radiations is clearly a vital element in scientific research. Hence in mid-1959 agreement was reached with Euratom, the United States and Canada to set up a European-American Nuclear Data Committee to ensure scientific co-operation between member and associate countries of ENEA in the measurement of nuclear properties of general importance. This decision followed the announced intention of the members of the Tripartite Nuclear Cross-Section Committee (Canada, United States and United Kingdom), to extend co-operation to all interested Western European countries. The organization of the Nuclear Data Committee is closely modelled on that of the T.N.C.C., and the fact that membership of the two Committees is in part the same should help towards a close co-operation in their work.

The first task of the committee was to make a critical review of the existing state of knowledge in order to highlight the gaps in relation to the needs of atomic energy programmes, and for this it assembled all available data and measurements of nuclear cross-sections and other basic nuclear data. The committee intends to review facilities, techniques and manpower, and recommend appropriate action. Where necessary it will recommend the pooling and exchange of equipment and personnel. A special group set up in ENEA will prepare the work of the committee

by collecting all useful information on programmes and their advancement and available facilities and needs, and will ensure the circulation of the committee's reports, studies and recommendations.

Measuring stations have been set up or are planned in most countries in order to check variations in environmental radioactivity. In view of the importance of this subject for European countries, ENEA has established machinery for the exchange and circulation of information provided by these stations; the effective comparison of this data will call for a certain standardization of methods and units of measurement. This machinery will make it possible to keep a watch on variations in radioactivity in Europe, and to alleviate the fears of a sometimes ill-informed public as well as to give warning of any dangerous increase which may take place in contamination.

Legislative and Social Problems

The efforts made by ENEA to encourage, on the scientific and technical plane, the development of the use of nuclear energy for peaceful purposes must necessarily be supplemented by the adoption on the European scale of measures designed to meet the special risks arising out of this new form of energy. The OEEC countries, by a decision of the council in June, 1959, undertook to take the necessary measures to ensure effective protection for workers and the population as a whole against the dangers of ionizing radiations wherever radioactive matter is produced or used. In principle, these measures should be founded on health protection norms prepared by ENEA and approved by the Council, which determine the maximum permissible doses for persons occupationally exposed in nuclear installations or controlled areas, the permissible concentrations of radioisotopes in water and air, and the maximum radiation to which the population as a whole may be exposed.

Member countries also undertook to report periodically to ENEA on the legislative or administrative arrangements made or to be made to fulfil their obligations under the decision. These reports, in which countries must specify the instances where they have departed from the approved norms and the reasons, will be examined and discussed at ENEA in order to assess whether the action taken ensures adequate application of the norms.

Immediately on the creation of ENEA, an international convention on security control was signed by all OEEC countries, so that the joint action undertaken could not further any military purpose. This Convention came into force on July 22, 1959. The control is essentially the obligation of accounting for fissionable material used and supervision by international inspectors. The control will be administered by an international bureau set up as part of ENEA. Sanctions may be applied in the event of an infringement, subject to the right of appeal by the states or undertakings concerned to an international tribunal specially set up for the purpose.

Finally, ENEA has devised an international convention on third party liability in the field of nuclear energy, designed to provide compensation for injuries arising out of nuclear incidents under conditions which take account of the technical, economic and financial situation of this new industry. The draft of this Convention, now submitted to the OEEC Council, provides for the absolute (i.e., independent of proof of fault) and exclusive liability of the operator of a nuclear installation in the event of an incident arising either in his installation or during the carriage of fuel originating therein. The amount of the operator's liability is limited to $15 million, which represents the maximum amount which can in practice be covered by insurance, and operators are obliged to have insurance or other financial security up to this amount. Injured persons cannot bring a claim for compensation after the expiration of 10 years from the date of the nuclear incident; finally, a single court, namely that having jurisdiction in the place of the incident, is competent to determine all the actions arising out of the same incident, and the judgments delivered have executory force in all OEEC countries.

This survey of ENEA's activities does not claim to be exhaustive; its aim has been rather to highlight the principal fields in which ENEA acts as a centre for scientific, technical and legislative co-operation in the peaceful uses of atomic energy. ENEA has, for example, on its programme a continuing study of the trend of heavy water requirements in Europe and the possibility of producing heavy water in Iceland using the local sources of geothermal steam.

Similarly ENEA, all too conscious of the inadequate number of nuclear scientists and engineers trained in Western Europe, is attempting to help the development of teaching by special courses, for example those held at Harwell and Saclay, and special symposia. ENEA also publishes annually a catalogue of courses in nuclear energy in OEEC countries.

The initial work of the OEEC European Nuclear Energy Agency as outlined in this article is far from answering all the questions raised by the development of the nuclear industry. The complexity and urgency of the problems necessitate international understanding and co-operation if they are to be solved. Various other international organizations concerned, notably Euratom and the IAEA, are also engaged in trying to solve the problems, and as a result of the close liaison between ENEA and these organizations much progress has already been possible.

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Halden Reactor

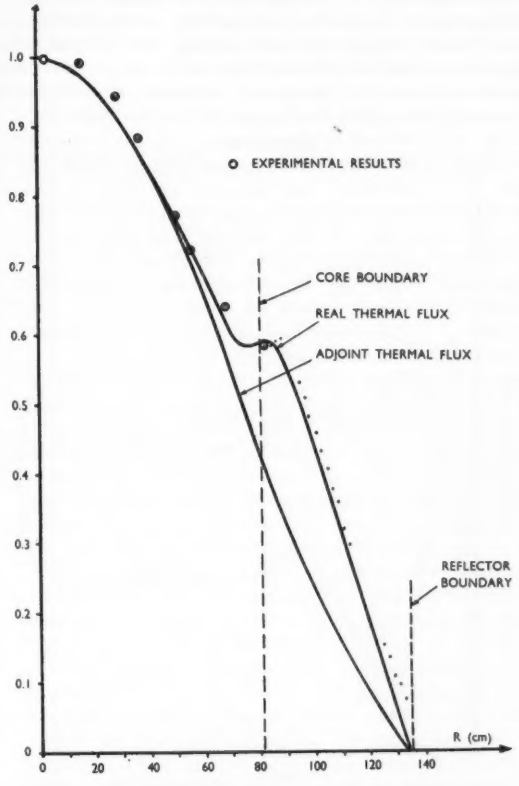
By HENRIK AGER-HANSSEN
(Chief of Research, OEEC Halden Reactor Project)

The Norwegian Institutt for Atomenergi, Halden.

THE Halden Boiling Water Reactor, built by the Norwegian Institutt for Atomenergi, has, since July 1, 1959, been operated jointly by a number of European Countries (Norway, Austria, Denmark, Euratom [on behalf of Belgium, France, Germany, Italy, Luxembourg and the Netherlands], Sweden, Switzerland and the United Kingdom) as an OEEC Project. The international agreement between these countries provides for a three years' joint programme of research and experiments. It is possible that this programme may be extended for a further 18 months.

The syllabus includes experiments on two fuel charges. On the first fuel charge, which consists of natural metallic uranium elements canned in aluminium, the reactor will be brought up to a power of 5 MW at a primary steam pressure of 5 at. With the second fuel charge, which will consist of uranium oxide elements canned in Zircaloy, the reactor will be brought up to a power of 20 MW at a primary steam pressure of 30 at.

In the first year of the international programme the assembly work on the plant was completed, the reactor was commissioned and precritical tests were performed. The international staff was gradually built up in this period.



Flux distribution for core assembly with 124 loading.

Criticality was achieved for the first time on June 29, 1959. From this date and until the middle of January, 1960, a low-power experimental programme was carried out. The reactor was then shut down for modifications before bringing the reactor up on full power. The experimental power programme is scheduled to start in early autumn this year.

The low-power and low-temperature programme[1] on the reactor involved experiments on two core assemblies consisting of 124 and 296 fuel rods respectively. The experiments on the 124 loading were designed to give data of importance for the operation of the second charge. Particular attention was paid to measuring the fast neutron attenuation in the D_2O reflector to enable an evaluation of the radiation damage in the tank wall during second charge operation. The second charge will have a heavy-water reflector of approximately the same size as for the 124 loading.

A complete evaluation of the thermal flux distribution was carried out in order to determine the reflector savings for this core geometry. In addition, important reactivity effects, like the removal of rods, the water level reactivity coefficient, and temperature coefficient at room temperature, were measured.

Besides giving useful information on the second charge, it was considered important that the first experiments with the reactor should be carried out with a small excess reactivity in the system. The experience gained proved very useful in preparing and carrying out the trials with the 296 loading.

The programme on the 296 loading, which is the final core configuration, has so far involved the following experiments:

(a) Control-rod testing.
(b) Thermal flux distribution: relative and absolute.
(c) Temperature coefficient at room temperature.
(d) Removal of rods.
(e) Water level reactivity coefficient as a function of water level.
(f) Void coefficient.

Particular emphasis was placed on a detailed investigation of the void coefficient. The measurements were carried out by pneumatically oscillating the water level confined between two annular channels around a fuel element. The reactor response to these oscillations was analysed with pile oscillator electronic equipment and the results interpreted in terms of reactivity units using a calculated zero power transfer function. The water level could be oscillated to any depth in the reactor. An analysis of the measuring technique has shown that it is possible to construct an integral void coefficient from the differential measurements.[2]

Parallel with the measurements in HBWR, an experimental programme on the effects of introducing foreign elements in a reactor lattice was initiated in co-operation with the Swedish AB Atomenergi. These measurements were carried out with seven of the slightly enriched uranium oxide cluster-elements which are to be used as

spikes in HBWR during power operation with the first fuel charge. The Swedish Zero Power Facility RO was used for the experiments.

The low-power programme established that 4.2% excess reactivity is available in the cold and unpoisoned reactor. An extrapolation from the RO measurements boosts this figure up to 5.4% with all seven spikes placed in the central zone of the reactor. This degree of tolerance will be sufficient for running the planned power programme on the first fuel charge.

A low-power—high-temperature programme will be carried out before the reactor is brought up on power with the first fuel charge. The main part of this programme is the measurement of the temperature dependence of the void- and temperature-reactivity coefficients. During these measurements the reactor will be electrically heated. The void reactivity coefficient will be measured up to about 80°C and the temperature coefficient all the way up to operating conditions (150°C). It has been difficult to develop a method for the measurements of the void coefficient which can be used above atmospheric pressure, and this has resulted in the strong temperature limitation for these measurements.

Much effort has gone into the planning of experiments relating to the study of the dynamic characteristics of the reactor. Theoretical models of the plant dynamics have been studied in both a Ferranti Mercury digital computer, available at the Norwegian Defence Research Establishment, and a Pace analogue computer, available at the Kjeller Research Centre of the Norwegian Institutt for Atomenergi.

The main objectives of the power operation of HBWR is to study the dynamic characteristics, the experiments being of the perturbation type. The response in one of the reactor parameters due to the perturbation in another reactor parameter is measured and analysed. Three different types of perturbation experiments are planned for HBWR. First, the reactivity can be oscillated and the power transfer function obtained. Second, the steam load can be changed, and third, variations in the sub-cooler power can be introduced.

The void distribution will distort the neutron flux distribution in the core. Determination of the neutron flux distribution will be made axially and radially at full power to determine the maximum specific power density. The maximum reactor power output that can be attained without fuel element burn-out will be calculated from these data.

Analysis of the reactor flux noise which occurs during boiling will be measured and analysed. Experiments carried out in the Argonne Experimental Boiling Water Reactor (EBWR) have shown that there may be a correlation between the boiling noise spectrum and the reactor core parameters. It is hoped that the boiling noise analysis might ultimately offer a simple method for predicting the power at which the reactor will become unstable.

Special efforts are being made to develop an instrumented fuel assembly for in-pile measurements. The fuel assembly will be equipped with instruments for the measurement of rate of coolant circulation, degree of subcooling, power distribution along the assembly, fuel cladding temperature and void content.

Instability problems encountered in reactors of large size and high power densities justify the development of in-pile instrumentation. To tackle the problem of the development of in-pile instrumentation on an international basis, the project has started co-operation with other research groups in Europe occupied with this new field.

A programme for studying irradiation damage to the structural materials of the reactor vessel has been planned. A large number of test samples have been made from reactor lid material, weld material and reactor tank material. These samples will be distributed in 10 containers placed inside the reactor tank near the tank wall. The containers will be taken out one by one as required for keeping a close current estimate of irradiation effects on the samples, and consequently on the tank itself.

An important aspect of the metallurgical and chemical programme will be the investigation of corrosion effects on the primary system structural materials. To facilitate this study, a special container has been placed in a by-pass circuit in the sub-cooler loop. In this container corrosion tests of materials in flowing reactor water will be made.

The experience obtained through the power operation of the two fuel charges will ultimately be used in an optimization study of the heavy water boiling reactor.

To facilitate such a study, the reactor physics parameters are examined over a large range of fuel to moderator ratio. The first charge elements have been extensively studied in the Swedish-Dutch-Norwegian experimental facility ZEBRA. The characteristics of the second charge elements will be studied in the Swedish RO reactor and the Norwegian Zero Power Facility NORA.

For the first charge, the heat transfer and hydrodynamic parameters were studied in a heat transfer loop using an electrically heated element at the Technical University in Delft, Holland. Similar measurements will be carried out for the second charge elements at the Technical University in Eindhoven, Holland.

The above experiments, together with the information obtained from the experimental programme on HBWR, will strongly support the optimization study. The experience gained in all phases of operation of the reactor, like heavy water leakage through valves, pumps and other equipment, radiolytic dissociation of the water and radioactive carry-over to the steam, represent also important information for an evaluation of the reactor concept.

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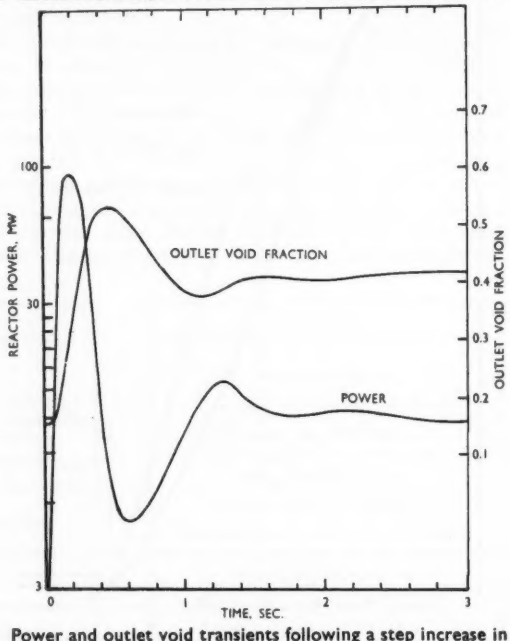


Power and outlet void transients following a step increase in reactivity of 1%.

THE EUROCHEMIC COMPANY

1.—Organization and Activities

By Dr. ERICH POHLAND
(General Manager, The Eurochemic Company)

THE Eurochemic Company—which will carry out all forms of industrial research and activity connected with the processing of irradiated fuels—has now begun the actual construction of a reprocessing plant and a research laboratory at Mol in Belgium. This is the culmination of discussions and preparatory work extending over several years.

The Eurochemic Company grew out of the work of a study group set up by OEEC in 1956. After examining Europe's needs in connection with the chemical processing of irradiated fuels, this group defined the broad outlines of a pilot undertaking—including the capacity and general design of the reprocessing plant, the choice of site, the institutional form and mode of financing. On December 20, 1957, the twelve OEEC countries interested in the project (Austria, Belgium, Denmark, France, Germany, Italy, The Netherlands, Norway, Portugal, Sweden, Switzerland and Turkey) signed a convention establishing the Eurochemic Company with a capital of $20 million to be located at Mol near the installations of the Belgian Centre d'Etude Nucléaire. A thirteenth country, Spain, acceded to the convention in 1958, thus increasing the capital to $21.5 million. The inauguration of the convention was made subject to its ratification by a sufficient number of signatories and the company became legally constituted when this condition was fulfilled on July 27, 1959.

In order to avoid delay the OEEC decided long before this date to start the preparatory work connected with the company. The powers of the study group were extended for this purpose and it provided the setting for the work. It also appointed an interim board of directors and a technical management committee. A team of engineers and technicians were recruited and in the second half of 1958 they started work in offices and laboratories rented by the OEEC from the Belgian Centre d'Etude Nucléaire. Immediately on formation the company profited directly from this work and also found itself with a nucleus of technicians and scientists.

To carry out this first international undertaking of an industrial character the countries taking part chose the legal form of an international company limited by shares. This is a quite novel kind of institution involving both international law and commercial law. The international convention establishing the Eurochemic Company thus provides legal personality and capacity and determines its status; the statute appended to this convention lays down the rules for its organization and operation.

In this way the company is governed by public international law and the signatory governments continue to exercise a certain amount of supervision through the special group of the Steering Committee of the European Nuclear Energy Agency. This special group consists of Government representatives. It takes decisions which are binding on the company, either unanimously or by a simple or qualified majority. It must approve certain decisions which are particularly important to the company, such as the processing of fuel from non-member countries or the delivery of special fissionable materials to such countries, and the construction of a new larger plant, together with any amendment to the statute and any increase of capital which would change its distribution between the shareholders. Any difficulties encountered by the company in its work arising, for example, out of legislation in the headquarters state are also submitted to the special group. Lastly, the company must submit to the special group an annual report on its activities and financial position.

The company's position under public international law is also illustrated by certain privileges and exemptions set out in the convention, such as the inviolability of installations, freedom from seizure of materials necessary for its activity, exemption from direct taxes and customs duties, exchange facilities, etc.

If the Eurochemic Company were governed solely by rules similar to those of other international organizations whose activities are purely administrative or financial, it would find difficulty in pursuing its industrial objects. This explains why it was organized in the form of a company limited by shares, in accordance with the concepts of commercial law.

The form of a company limited by shares allows great

EUROCHEMIC'S SHAREHOLDERS

Shareholders	No. of shares
The Government of the Federal Republic of Germany	50
Rheinisch-Westfälisches Elektrizitätswerk (RWE), Essen	1
Arbeitsgemeinschaft Deutscher Energieversorgungsunternehmen zur Vorbereitung der Errichtung eines Leistungs-Versuchs-Reaktors e.V. (AVR), Düsseldorf	1
Grosskraftwerk Mannheim AG., Mannheim-Neckarau	1
Steinkohlen-Elektrizität AG. (Steag), Essen	1
Badenwerk AG., Karlsruhe	1
Bayernwerk AG., München	1
Hamburgische Elektrizitätswerke AG., Hamburg	1
Preussische Elektrizitäts-AG., (Preussenelektra), Hannover	1
Kraftübertragungswerke Rheinfelden/Baden	1
Allgemeine Elektrizitätsgesellschaft (AEG), Frankfurt/Main	1
Interatom, Bensberg b. Köln	1
Degussa, Frankfurt/Main	1
Metall-Gesellschaft AG., Frankfurt/Main	1
Brown, Boveri & Co. AG., Mannheim	1
Farbwerke Hoechst AG., Frankfurt/Main Hoechst	2
Farbenfabriken Bayer AG., Leverkusen	2
The Government of the Republic of Austria	20
The Government of the Kingdom of Belgium	17
Société Belge de Chimie Nucléaire (BELCHIM)	27
The Government of the Kingdom of Denmark	22
The Commissariat à l'Energie Atomique, Paris	46
Société Saint-Gobain	22
The Comitato Nazionale per le Ricerche Nucleari, Rome	37
SORIN	5
SENN	2
The Government of the Kingdom of Norway	20
The Government of the Kingdom of the Netherlands	29
NERATOOM	1
The Junta de Energia Nuclear, Lisbon	6
Aktiebolaget Atomenergi, Stockholm	32
The Government of the Swiss Confederation	30
The Government of the Turkish Republic	16
The Junta de Energia Nuclear, Madrid	30

flexibility in its composition. The shares, though registered in the name of the holder, may in fact be transferred with the agreement of the general assembly. The capital, which is divided into 430 shares, is at present held by governments, public or semi-public bodies, with about 20 per cent by private undertakings.

This form also facilitates the shareholders' right to express an opinion on any decision taken by the company. The supreme body of the company is a general assembly consisting of all the shareholders, who take decisions by a majority, each share carrying the right to one vote. This general assembly exercises the same kind of functions as the general meeting of an ordinary limited company; it appoints the board of directors and the board of auditors, approves the management and the accounts, decides on the paying up of shares, amends the statute, etc.

The role of the board of directors is also in accordance with normal practice; it manages the business of the company and, as regards day to day administration delegates its powers to a general manager. The board of directors has, in addition, set up a scientific and technical committee of experts from the participating countries to advise the company on major technical problems and the research programme.

The general manager runs the affairs of the company in accordance with rules laid down by the board of directors, in particular the rules of management which ensure that the board retains its responsibility for major decisions such as the appointment of managers, delegation of powers, conclusion of contracts relating to the processing of fuels and the delivery of special fissionable material, loans, agreements with international organizations, and adoption of the annual programme and accounts.

The Eurochemic Company is subject, where the convention and the statute are silent, to the law of the headquarters state, and this is another respect in which it departs from international law. Belgian law applies mainly to relations with third parties, and the normal legal transactions of an industrial concern such as buying and selling, leases, engaging labour, etc.—and to its third party liability.

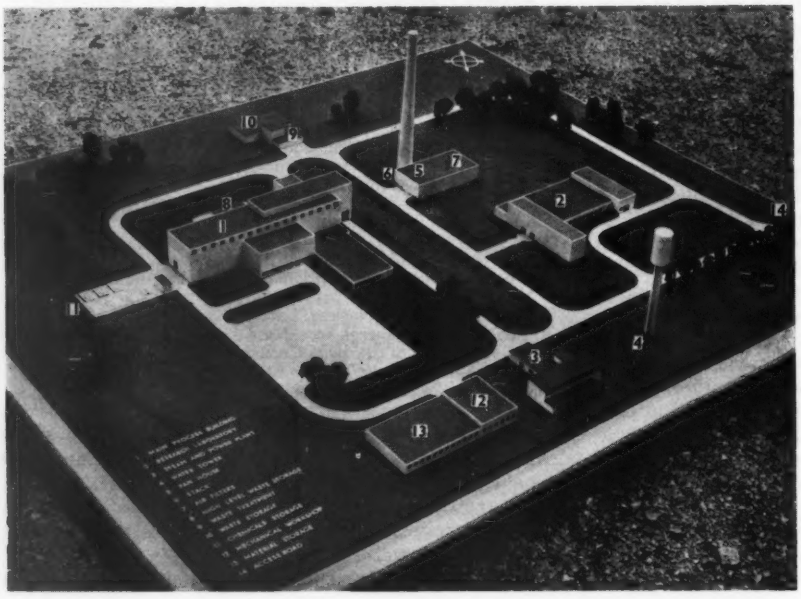
This duality, which is made necessary by the nature of the company, also constitutes one of the difficulties of the experiment; a delicate balance must be maintained between the international character of the company and its necessary integration into the legal and economic life of a particular country. This not only raises complex legal issues but also problems of general policy.

It is essential that every shareholder should share fairly in the benefits arising out of the joint undertaking. This means that technical knowledge acquired must be passed on in ample measure to the shareholders, and the rules for circulating information must not be unduly influenced by the protectionist practices often prevalent in industry. Sending trainees is one of the ways in which shareholders acquire experience, the number of places being allotted in accordance with the distribution of the authorized capital.

In the same spirit industry and technicians in the various European countries must be given a fair share in the construction and operation of the plant and the research laboratory. For the construction of its installations the company is therefore calling upon leading firms of consultant engineers in the participating countries, and they will collaborate on the detailed studies and supervision of the site. The company—with a view to international competition—will also invite tenders from a great many European contractors.

Once the plant is operating, shareholders must be able —within the limits of the available capacity—to have their irradiated fuel elements processed there and to receive the regenerated fuel after processing. Suitable safety precautions and regulations will have to be laid down for the carriage of these fuels.

These few examples show, if need there be, that the problem of the shareholders does not arise for the management of the Eurochemic Company in the usual terms. Moreover, precisely because of its special circumstances the proper functioning of the company is strictly conditioned by the understanding shown by national authorities, especially those in the headquarters state. For this reason the convention obliges them to take all necessary steps to assist the company in its operations.



Model of the new Eurochemic processing plant.

KEY

1.—Main process building.
2.—Research laboratory.
3.—Steam and power plant.
4.—Water tower.
5.—Fan house.
6.—Stack.
7.—Air filters.
8.—High level waste storage.
9.—Waste treatment.
10.—Waste storage.
11.—Chemicals storage.
12.—Mechanical workshop.
13.—Material storage.
14.—Access road.

THE EUROCHEMIC COMPANY

2.—*Technology, Design and Construction*

By Dr. ROMETSCH
(*Technical Director, The Eurochemic Company*)

THE long-term interest of Eurochemic is the economic reprocessing of irradiated fuels from nuclear power stations; the immediate interests may be summarized as follows:—

(a) to gain experience in the building of a reprocessing plant.
(b) to gain experience in operation and, in particular, to collect all possible information on the technical and economic conditions for the regeneration of uranium and the production of plutonium, with a view to a future commercial production stage.
(c) to obtain development results from research work on aqueous reprocessing and to train personnel for the industrial handling of large amounts of radioactive chemicals.
(d) to obtain purified fissionable and fertile material.

To meet all these expectations, it was decided to build a relatively small development-production facility, i.e., somewhere between a pilot unit and a real production plant. In fact, this plant will have important work to do in the recovery of fissionable and fertile materials from irradiated fuels and in addition must be able to collect development results under various operating conditions.

During the final design stage and the first construction period, a small but extensible research laboratory will be completed. The installation of the necessary auxiliary facilities was started with the erection of an office building; the most important will be a waste treatment plant.

Plant Pre-project

The plant capacity could not be determined by simply adding together the reprocessing needs of the participating countries. It was, for example, anticipated that the total needs announced in 1956 would decrease as reactor programmes slowed down. A greater difficulty stemmed from the fact that Eurochemic would have to treat a variety of fuel elements, with different cladding materials and dimensions which would be known with certainty only as the reactor programmes developed. Clearly it was not easy to obtain accurate information relating to time-schedules for the delivery of the irradiated fuel elements, which would serve to establish a rational planning of reprocessing programmes, grouping the fuel elements according to enrichment, irradiation, cladding and core materials. Without this data it would be impossible to establish a correlation of reasonable accuracy between equipment size and annual capacity. It was decided, in the end, to limit the size of the plant to a nominal capacity of 350 kg/day for aluminium-canned and magnesium-canned natural uranium, which may decrease to 200 kg/day for assemblies of the PWR type with Zircaloy or stainless-steel cladding.

Preliminary limits were also set for the range of characteristics of fuel elements to be accepted; namely 5% enrichment and 10,000 MWd/t irradiation, with cladding of Al, Mg, Magnox, Zr. Zircaloy and stainless steel, and core materials of U metal, UO_2, U-Mo alloys up to 10% Mo and, later, U-Zr alloys. Dimensions were limited to a maximum length of 250 cm (eventually 310 cm) and a maximum diameter of 19.3 cm.

Flowsheets

The basic flowsheet adopted is of the Purex type with two cycles. Tributyl-phosphate is used as solvent, as a 30% solution in a hydrocarbon diluent. Recycling of effluents is envisaged wherever possible to keep the waste streams to a minimum.

Compared with a conventional Purex flowsheet, some modifications had to be introduced to meet the required flexibility. Thus, for instance, in order to make the treatment of enriched fuel possible, without being obliged to install geometrically safe equipment throughout the plant, a dilute feed—0.6 M in U—was chosen for the extraction. These operating conditions permit both a high decontamination factor to be reached, and a maximum extraction yield.

The decontamination and the separation of uranium and plutonium will be achieved in a group of five columns. This part of the installation will have nearly all the characteristics of a production plant as it is based on well-established procedures. The main decontamination takes place in the first two columns HA and HS where the principal controlling parameters are:

Acidity of the feed solution, which is kept between 1.5 M and 2 M nitric acid at the feed plate. This is a compromise value, in order to assure a certain decontamination of Zr, Nb and Ru, as well as a good U-extraction;

Saturation of the solvent, which is adjusted to about 79% by the solvent flow;

Scrubbing, which is accomplished by two different acidities and two different temperatures, in order to reach separately the most favourable conditions for Zr-Nb- and Ru-decontamination.

The separation of U and Pu is again split in two columns 1BX and 1BS, both working at low acidity. It is proposed to recycle organic phase from 1BS to HA-column, which will result in decreasing possible Pu-losses in the organic U-stream. From 1BS the Pu-containing aqueous phase is led to the Pu tail-end treatment, whereas the U passes, after stripping in the 1C-column and evaporation, to a second decontamination cycle of two columns. The final purification of U is accomplished by silica gel adsorption.

The plutonium tail-end purification will either be effected by counter-current extraction with tertiary amines, or by an ion exchange. The decision depends on the results of investigations at present being carried out in the research laboratories.

The head-end part of the Eurochemic plant will necessarily be pilot in character. A series of different decladding procedures will have to be applied, some of which have not yet been tried out in practice with highly

irradiated fuel elements. The following methods are foreseen:

For Al cladding: sodium hydroxide dissolution.

For Mg or Magnox cladding: sulphuric acid or dilute nitric acid dissolution.

For Zr. or Zircaloy-2 cladding: Zirflex process, i.e., ammonium fluoride ammonium nitrate dissolution by 4 M sulphuric acid.

For U and UO_2 cores: fumeless dissolving by nitric acid.

For U-Mo alloys with Mo content up to 10%, a special procedure has been developed to recover the uranium and plutonium adsorbed on molybdic acid precipitations.

Equipment

Equipment specifications were laid down to meet the requirements of primary importance, such as safe containment, decontamination possibilities and criticality control.

In practically the entire plant, the principle of double containment will be realized by having the equipment installed in concrete cells, the bottom and at least part of the walls of which are covered by a tight stainless steel lining forming a secondary containment. By means of rigid specifications, a careful control will be exercised in the selection of equipment, as well as in the choice of adequate construction materials and manufacturing techniques. Furthermore, leak detectors will be installed in selected positions to give immediate alarm in case of equipment failures.

Where maintenance, modifications or repairs are necessary, the process equipment could be decontaminated, partly or completely. Provision will be made for a remote control system for make-up and distribution of decontamination liquids including the spraying of equipment interiors, outside surfaces and cell walls. In the design of equipment care is being taken to avoid inaccessible spaces, crevices, etc., which cannot be reached by decontamination liquids.

Since the plant must be capable of processing enriched fuels up to 5% U^{235} at high irradiation levels, criticality control is a very important design consideration. For economic reasons, the feed adjustment and clarification system has been designed for concentration limitation, rather than mass or volume control. However, varying degrees of solvent saturation in the first cycle, the ratios of strip to solvent volumes chosen and the conditions which may possibly arise when the plant is not operating at flowsheet rates, make it necessary to anticipate concentrations higher than those permissible. Hence, all the equipment items of that section will be of safe geometry. The second cycle of U-extraction, as well as the U tail-end, will also be installed with geometrically safe equipment wherever concentrations may reach, or exceed, the critical limits.

Research Programme and Laboratory Planning

The Eurochemic reprocessing plant was planned as a development unit not only to provide flexibility, but to establish adequate research laboratories to investigate possible improvements of the process and the testing of equipment and instrumentation.

It is realized, however, that the research facilities to be constructed will not be ready in time to provide the information necessary for the first installation of the plant. A research group has therefore been set to work during the interim period in laboratories rented from the Belgian Centre d'Etudes Nucléaires (C.E.N.).

Here, the applied chemistry section has undertaken to test all parts of the envisaged flowsheet. The preliminary head end parameters are determined on unirradiated samples. Extractions are carried out on a semi-hot scale in shielded, remotely controlled mixer-settler batteries and the different solutions for the tail-end processes are tested with pure plutonium solutions and suitable synthetic mixtures.

In addition to providing the necessary analytical results for the flowsheet testing, the analytical section is at the same time reviewing, experimenting with and developing the analytical procedures for the plant. Great importance is also given to the testing of equipment components, e.g., transfer equipment such as steam jets and air lifts and, particularly, the extraction equipment. For this reason a testing station has been built, comprising plant-size pulse columns for the extraction and stripping of uranium. These column efficiencies are under investigation, with different pulsing methods, using inactive solutions.

The long-term research programme to be followed in the Eurochemic facilities comprises the investigation of improvements in present reprocessing techniques, development of alternative processes, or process steps, of new instrumentation possibilities (e.g., analytical in-line instruments), and the testing of new methods in pilot units.

The laboratory planned for the first stage will be rather small, but possibilities for extension are being carefully considered. The following areas of different activity levels are envisaged, according to the various categories of work:

Cold labs for inactive and tracer work up to 10 μc,

Hot labs for medium activity up to 10 mc and high activity up to 10 c,

Hot cells for work with activities up to 10^4c,

Alpha labs with an upper limit of 500 mc.

In addition, a chemical engineering hall is contemplated where medium activities can be handled using unit shielding.

Waste Treatment

It is the task of the Eurochemic waste treatment service to take care of the total activity discharged from the plant and the laboratory. This task is complicated by the fact that only very limited amounts of activities—1.5 weighted curies per month for the combined Mol institutes—are allowed to be released into the small stream in the neighbourhood of the site.

The high-level waste containing the bulk of the fission products will be concentrated in the plant, and stored in underground tanks on the site. Medium-level waste, like the decladding solutions and the hot waste from the laboratories will be treated and concentrated in a special waste treatment plant and also stored on the site. It is proposed to send the warm waste of an average total daily beta-activity of 200 mc in a volume of approximately 50 m^3 to an industrially operated waste treatment plant common to the C.E.N. and Eurochemic.

State of Progress

Construction on the site has been started with the first auxiliary building. An engineering contract has been passed to a French company to work out the pre-project into more details, and a series of engineering contracts are under negotiation with companies in different member countries, to allow for a broad distribution of the construction experience in the field of nuclear chemical installations.

Construction of the research laboratory is scheduled to begin at the end of this year; that of the plant itself in summer 1961. In 1963, plant test runs are foreseen, so that the actual operation of the plant would commence in 1964.

DRAGON

Organization

by C. A. RENNIE
(Chief Executive, OEEC High Temperature Reactor Project, AEE, Winfrith.)

THE HTGCR or DRAGON project at Winfrith, arose out of discussions between the representatives of 12 European countries, including the six members of Euratom, which were held under the auspices of the European Nuclear Energy Agency of OEEC. In the course of these discussions on the setting up of a joint project, the United Kingdom offered to make available the information on the AEA's high-temperature reactor work and to house the joint project at AEE, Winfrith. This offer was accepted by the other countries and an agreement for a joint programme of work was signed in March, 1959, to take effect from April 1, 1959, for a period of five years. This agreement covers a programme of research and development work and also the construction of a reactor experiment. The whole undertaking is estimated to cost £13.6 million, which is to be shared out between the signatories in an agreed manner.

The form of organization of the joint project stems from the fact that it was agreed, in order to avoid creating a new legal personality, that all legal acts relating to the carrying out of the project should be performed by the U.K.AEA. This meant that it was possible to proceed almost immediately, whereas if it had been necessary to create a new organization with its own legal personality then this would have taken a considerable time. For instance, it was possible immediately, once funds had been voted for the project, to make arrangements with the Authority to carry out certain services on a repayment basis, and also to carry on the work already started by the AEA. For this reason, the project is organized in a rather different manner from other international projects, as it does not need to have the complete administrative organization, which would be necessary if it was a legal personality of its own.

One of the first tasks was, of course, to get together the necessary staff. Before this could be done, there had to be agreement about the method of payment and a device was adopted which seemed to fit the particular circumstances. As it has no legal personality, the project cannot be an employer in the usual sense, and therefore it has been arranged that all the staff are seconded to it from their parent organization or employer. When seconded in this way the staff are, of course, subject to the conditions of service of the project, but are still employed by the organization from whom they were seconded.

This has led to a rather different staff structure than is usual. Each post carries a certain grade, but the project does not pay a salary directly to anyone: instead it pays the agreed amount for a given grade to the signatory from whom the man, or woman, is seconded. In this way it is possible for the staff to retain their superannuation rights and their long-term career prospects.

The staff are organized into three divisions—research and development, engineering and administration. The first two will each have about a hundred people with about 50 in the latter, giving a total strength of about 250 people at Winfrith. The effective strength is larger as services are obtained from AEE, Winfrith on a repayment basis.

Under the division heads, there are a certain number of deputies—three in the case of research and development, five in the engineering division and two in the case of administration. These staff, together with the division heads and the chief executive, totalling 14 in all, make up the senior staff. Of the 14 senior staff, seven are from the U.K. and seven from other countries.

The chief executive is responsible to the board of management for the running of the project, and the board itself, consisting of representatives from the signatory countries, normally meets three times a year. A general purposes committee, again comprising members from each of the signatory countries meets four times a year.

The staff, other than the senior staff already mentioned, are appointed by the chief executive: so far about 80% of the vacancies have been filled.

The U.K. agreed to make available the information which had been obtained by the Authority prior to the date on which the project was set up. This has been done in several ways. One way was by seconding many of the staff, who had been working on the high-temperature reactor. In addition, information was made available through unpublished reports, memoranda, etc., which were for U.K.AEA use only. The project was also able to take over contracts, which the AEA had already placed in connection with their high-temperature reactor work. Certain facilities, which were being constructed for the Authority, such as the High Temperature Zero Energy Reactor ZENITH, an irradiation loop for the PLUTO reactor and a mass transfer loop will be made available to the DRAGON team on a rental basis.

As the project has no legal personality it is necessary for the Authority, acting as the agent of the project, to sign any contracts. The project then authorizes the money from its own funds, and is responsible for the technical content of the contract. As the legal agent of the project the Authority is responsible for seeing that the contract is legally sound.

Wherever possible work is put out to competitive tender

DRAGON was officially inaugurated on April 27 this year. Our photograph shows the ceremony at Winfrith, Dorset.

in all countries. Because of the large number of possible suppliers in Europe, it is sometimes necessary to limit the number of firms. Signatory countries themselves are then asked to nominate firms to receive tender documents: in this way it is possible to obtain a representative selection of tenders for a given contract. Where the work involves the use of a considerable labour force on the actual site, tenders are sought only from British companies.

The DRAGON agreement provides that information arising from the project should be made available to the signatories, who are then responsible for any dissemination within their own countries. The project normally makes information available in the form of reports or memoranda. Besides publishing papers in the technical Press, the DRAGON team takes part in and organizes symposia on specialist topics. There are provisions in this exchange of information for the protection of inventions, if they are patentable. The project is encouraged to take out patents where applicable, and the terms on which these patents can be made available to the signatories and to other countries are laid down in general in the agreement and have been agreed in detail by the management. Arrangements have been made with the AEA to make use of its services on a repayment basis for taking out patents, etc.

An agreement has recently been concluded for an exchange of information and of visits between the DRAGON project and the United States High Temperature Gas Cooled Reactor Project.

As previously mentioned the present DRAGON agreement is for a period of five years. It is hoped that the reactor experiment, the construction of which started in April, 1960, will be completed by March, 1963, that is one year before the end of the present five-year agreement. Allowing for a period of some months for commissioning and loading and bringing the reactor up to power, it can be seen that the present agreement will only provide for a few months' operation of the reactor experiment. There is provision for an extension by mutual consent, but no decision has been taken as yet.

Objective

THIRD in the line of gas-cooled reactor concepts, the graphite moderated helium cooled system should allow the production of steam conditions comparable with those experienced in the most modern conventional stations with the additional advantages of a compact core (and a potential of low capital cost) and a means of exploiting the thorium-U^{233} cycle. Although ultimately the system may be extended to eliminate heat exchangers by gas turbines directly driven by the primary coolant gas, the sights are at present levelled on a high efficiency steam cycle and, at least, as an OEEC venture, research and development will not go beyond this concept. The system should be applicable to both small and large land base stations, and is favoured (by the United States at least) for marine propulsion.

The use of helium and the high temperature conditions call for a new approach to both core design and engineering structures. The conventional system of suspending metal clad fuel elements in coolant channels formed by spaces in the moderator has been largely dispensed with and the moderator (graphite) assumes the role of cladding and heat transfer medium. The use of graphite as a cladding material and the system of enclosing individual fuel rods in a graphite element allows a new approach to the containment and disposal of fission products. This has the advantage of both increasing the reactivity of the core and decreasing the total fission product hold up in the system—a significant advantage from the safety viewpoint. It should be possible to hold up the fission products produced within the fuel for a given time, permitting a considerable decay of activity before they seep through the inner wall where they are purged by the bleed stream and separated in the fission product extraction plant. Proper control of permeability of the inner tube and of the main graphite should decrease the load on the extraction plant and also maintain the total activity held up in the core to a relatively low level with little risk of back diffusion into the main coolant stream. The control of permeability of the graphite is far from perfect but so encouraging have been the initial results that much greater attention will now be paid to optimizing the purge rate. At one time it was a question of whether to aim for a strong hermetically sealed unit or a complete purge.

The use of such a fission product removal system would not be practicable in a low temperature reactor where conductive losses in the fuel-can interface are of serious import. At the temperatures envisaged the bulk of the heat transfer will be radiative and hence small gaps can be tolerated; similarly the specification for the fuel can be less rigorous, and cold compaction techniques and even homogeneous mixtures of uranium, thorium and graphite appear practicable.

From the engineering standpoint the use of helium (and its cost) requires a quite different approach from the techniques adopted in the Calder Hall reactors and in AGR, although not so very different from the philosophies favoured by Oak Ridge in the EGCR. For DRAGON,

TABLE 1

Fissile loading kg	20	20	20
Thorium loading kg	134.8	113.3	124.3
Boron-10 content ppm graphite	0	3.50	1.50
Graphite/U-235 ratio	2128	2131	2130
Thorium/U-235 ratio	6.83	5.74	6.29
Conversion factor	0.52	0.46	0.49
Running time/charge, days	390	510	390
Flux (initial) neutrons/cm² sec.	4.5×10^{13}	4.5×10^{13}	4.5×10^{13}
Thorium destroyed per year, kg	5.2	4.2	4.8
Thorium destroyed per charge, kg	5.5	5.9	5.1
U-235 destroyed/year	8.0	7.7	8.0
U-235 destroyed/charge	8.6	10.8	8.6
Burn-up MWd/kg U-235	388	508	388
U-233 produced	3.3	3.4	3.2
Initial reactivity	6.0	6.0	6.0
Reactivity due to xenon (25 days)	2.9	2.8	2.8
Temperature reactivity, %	5.2	4.7	4.9
Reactivity on shut-down in excess of 6%	—	1.2	0.0
Total control required	11.2	11.9	10.9

except where experimental flexibility dictates the use of flanged joints, an all-welded circuit is required, in practice made possible by the development of gas bearing circulators. These are totally enclosed in the primary circuit

Table 2 Temperature Coefficients in 10^{-5} C^{-1}

Temp. °K	Moderator	Fuel	End reflector	Side reflector
300	−9.6	−3.2	0.5	5.3
500	−7.5	−1.8	0.3	3.8
700	−5.9	−1.3	0.2	2.5
1100	−4.6	−0.8	0.2	1.3
1300	−4.4	−0.7	0.1	1.1

and use the coolant gas as the lubricant. Control rod drives are also totally enclosed.

Although the present design of DRAGON is substantially the same as that conceived by the AEA it has now been decided that the rating of the reactor should be 20 MW, in order to raise the volume rating of the core to a level which allows useful results to be obtained in two years of full power operation. The experimental demands for a high flux and a long fuel cycle without excessive initial reactivity investment has led to the decision to use a 20 kg loading of U^{235}. Theoretical calculations of the behaviour of the reactor with variable amounts of thorium and B^{10} content both as impurity in the graphite and as a burnable poison adding to the system are shown in Table 1. Figs. 1 and 2 show the reactivity against life for two levels of boron and indicate the investment that must be made for fission product poisoning.

The zero energy reactor ZENITH (*Nuclear Engineering*,

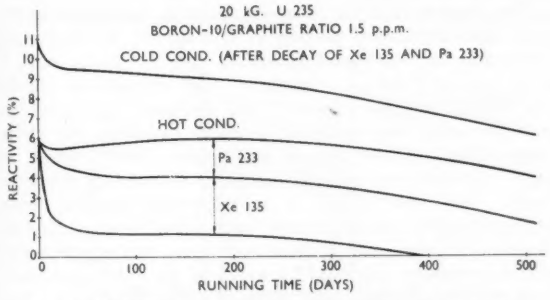


Fig. 1.—Variation in reactivity against running time with low ratio of boron.

November, 1959, pp. 386-393) will provide much of the physics data for DRAGON. Already significant results have been obtained from the experiment such as the appreciation that an over estimate has been made of the extent of streaming down fuel element and control rod channels resulting in a greater control rod worth than was originally calculated. When ZENITH becomes fully operational and is loaded with a core approximating to the first DRAGON core, measurements will be made on temperature coefficients both in the core and reflector, and in addition measurements of the thorium cross-section and spectrum will be attempted by extracting a beam from the reactor. Neutron life-time will be determined by an oscillator technique and a variety of perturbation measurements will be made.

The values of the temperature coefficients calculated are shown in Table 2. The predominating negative characteristics of the moderator and the fuel indicate that

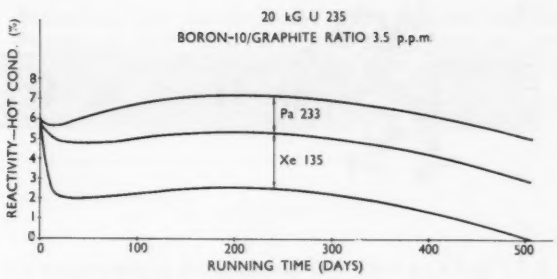


Fig. 2.—Effect of higher level of boron on reactivity.

the system should be stable. Fig. 3 shows the result of a ramp change in reactivity of 2% over 40 sec leading to a temperature rise in both moderator and fuel of approximately 450°C.

In the past, considerable attention has been given to forced convection heat transfer from surfaces, the temperature of which differed little from that of the fluid passing over them; less attention has been given to the state which would exist in DRAGON where the temperature differential will be large. As a result a great deal of heat transfer work is necessary: this is further complicated by the difficulty of conducting experiments at these high temperatures, in measuring temperatures with accuracy and in arranging for the measured parameters to show a reasonable heat balance. Various types of rig are being built or have been completed including a large high temperature rig by C. A. Parsons which will allow extensive tests to be made on a seven-element model. This will also give information on the mechanical behaviour of the core. Attempts have already been made to produce theoretical models which will explain the data collected so far on heat transfer, particularly in relation to an annular geometry. Further details of the C. A. Parsons test rig are given on page 316 of this issue.

Examination of fuels and graphite under irradiation has been carried on at Harwell for some time and this work is to be extended to cover in-pile, thimble irradiations and loopwork in DR-3 in Denmark, DIORIT in Switzerland, the Netherlands MTR, R-2 in Sweden and BR-2 in Mol.

In addition a great deal of research is being undertaken into engineering and instrumentation aspects of the plant such as the testing of bearings, work on control rod mechanisms, charge/discharge operation for which a machine is already under test as well as the large programme being assembled on the development of materials, particularly graphite.

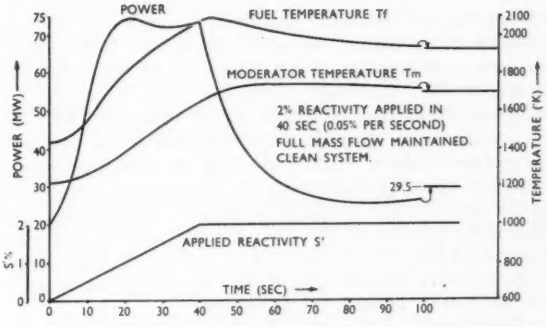


Fig. 3.—Application of reactivity in full power condition; (left) variation of power and applied reactivity; (right) variation of fuel and moderator temperatures.

General Description

ALTHOUGH work was first initiated at Harwell on the possibilities of a high temperature gas cooled reactor in 1956, it was not until the Geneva conference of 1958 that the outlines of the scheme were given in a paper* (*Nuclear Engineering*, October, 1958, p. 428). The project, which has since been named, most appropriately, DRAGON, was transferred to the O.E.E.C. on March 23, 1959, and construction has commenced at Winfrith Heath. The two major changes in the scheme which have taken place since publication of the original paper are the change in rating from 10 to 20 MWt, and the substitution of helium for the nitrogen coolant originally proposed.

The advantages of high temperatures, from the point of view of efficiency, scarcely need be mentioned. What distinguishes the high temperature reactor from all other gas-cooled types is the philosophy of fission product removal. At the temperatures visualized, no form of metallic canning could be entertained, so that the objective is not containment, but continuous removal of gaseous products.

General Description of Scheme

DRAGON is a 20 MW helium-cooled reactor operating with an upper coolant temperature of 750°C (approx. 1382°F). It is fuelled with a fissile-fertile mixture of uranium (enriched) and thorium carbides, in sintered compacts contained within graphite, acting as both canning and moderator. No generation of useful power is contemplated, the heat being rejected to atmosphere by means of air-blast coolers in the final (tertiary) coolant circuit. Double containment is provided, the internal container being filled with a nitrogen atmosphere, and regarded, for all practical purposes, as a "hot cell." The general arrangement of the reactor is shown in the pull-out drawing opposite page 308.

Core

The core design is the subject of a separate article elsewhere in this issue, and it will suffice to point out here that, as far as the active portion of the core is concerned, the fuel elements and the moderator are combined. In place of what is virtually a solid mass of graphite, into which the fuel elements are lowered, each fuel element consists of a cluster of seven hexagonal fuel rods of impermeable graphite, which practically fill the entire core space, coolant channels being provided by raised ribs down the centre of each face of the hexagon. The fuel, in the form of rings, is accommodated inside the rods, in graphite boxes, each containing six inserts around a graphite spine; the function of these inner boxes is to delay the emission of fission products. These boxes form the active portion of the core; a solid graphite portion at top and bottom of the rod act as reflectors. Each seven-rod cluster, or element, stands on a hollow spike, connected to the fission product purge system.

The radial reflector is in two portions; fixed and removable. There was, at one time an intention to use moving graphite rods to supplement the absorber rods, but it now appears that these will be unnecessary.

Control

The control system, like the core, is dealt with separately, and only a very brief description will be given here. Control is by means of 24 control or absorber elements which are constructed of concentric stainless steel tubes, packed with boron carbide. They are located around the circumference of the core, moving in holes in the "removable" portion of the reflector.

Control rod drives are located in positions of comparatively low temperature, being radially located around the reactor at an upper level, and driving the winding heads by transverse shafts, which raise and lower the rods by wire ropes, enclosed in shield tubes to protect them from the high-temperature exit gases. The motors and mechanisms run under gas pressure to obviate the difficult task of providing running seals; bellows seals are, however, provided for access to the hand-operated portion of the mechanisms, to avoid the escape of active gas when maintenance is being carried out.

Reactor Vessel

The reactor vessel is of unusual shape, taking the form of a main cylindrical portion 11 ft 6 in. (3.5 m) diameter, containing the core and reflector, with a "lower neck" 6 ft 3 in. (1.9 m) i.d., which is large enough to enable the charge machine to cover all the core and movable reflector, and give adequate vertical clearance for their withdrawal. Above this is an "upper neck," which is only 2 ft (0.61 m) i.d., and contains the charge machine itself. The vessel is not of one-piece construction, there being a bolted joint about half-way up the lower neck. The thickness of the main portion and lower and upper necks are, respectively, $2\frac{1}{4}$ in. (57.2 mm), $1\frac{1}{2}$ in. (38.1 mm) and $\frac{5}{8}$ in. (15.9 mm), the design pressure being 350 p.s.i.a. The

TABLE I.—Gaseous Activity Discharge to Stack

Isotope	Half Life	Discharge mc/Day
A 41	1.80 h	240.0
Ba 140	12.80 d	1.0
Br 83	2.40 h	5.0
I 131	8.05 d	0.7
I 133	20.80 h	14.0
I 135	6.68 h	33.0
Kr 83m	1.14 m	3.0
Kr 85m	4.36 h	12.0
Kr 85	10.27 y	0.6
Kr 88	2.77 h	36.0
Mo 99	67 h	4.0
Rb 88	17.80 m	36.0
Sb 127	93 h	0.1
Sr 89	54 d	0.2
Sr 90	28 y	3×10^{-5}
Sr 91	9.70 h	24.0
Sr 92	2.70 h	60.0
Tc 99m	6.04 h	4.0
Te 127m	90 d	1×10^{-3}
Te 129m	33 d	2×10^{-2}
Te 131m	30 h	7×10^{-3}
Te 132	77 h	3.0
Xe 133	5.27 d	3.0
Xe 135	9.13 h	8.0
Y 91	58 d	0.2
Y 93	10 h	26.0
Zr 95	63 d	0.2

* "The Possibilities of Achieving High Temperatures in a Gas Cooled Reactor." Geneva paper by L. R. Shepherd, R. A. U. Huddle, L. A. Husain, G. E. Lockett, F. Sterry and D. V. Wordsworth

weight of the vessel is 45.8 tons (45,533 kg) without the charging machine, which weighs some 3.5 tons (3,556 kg). The lower portion of the vessel (i.e., below the concrete shield plug) has been designed for a temperature of 400°C (approx. 753°F).

Coolant

Helium at 20 ats. pressure (294 p.s.i.) is used as the coolant, the temperature range of the reactor being from 350°C at inlet, to 750°C at the outlet. The general flow pattern of the coolant can be gauged from Fig. 1. By the use of concentric inlet and outlet ducts, and heat-resisting linings, all parts of the pressure vessel are kept at the lower temperature.

There are six coolant loops, arranged radially around the reactor, each being complete with its own blower and primary heat exchanger. On account of the heavy activity in the primary coolant, the use of double-walled heat exchangers was contemplated, but it was eventually decided that the use of double walls, while facilitating monitoring of any leakage, was more likely to be the cause of possible leakages, since it makes design much more complicated, and introduces many more stresses.

Each coolant loop is designed as a unit consisting of blower, or circulator, heat exchanger, by-pass valve, the general arrangement being as shown in Fig. 2.

The final design of the heat exchangers has not yet been completed but, after intensive studies of both boiling and non-boiling (pressurized secondary coolant) types, it has been decided to use the boiling type, with forced circulation.

The secondary coolant (water-steam mixture, at a pressure somewhat below that of the primary coolant gas) will transfer the heat to secondary heat exchangers located inside the containment shell, to eliminate possible troubles due to leakage of active gas into the secondary coolant. The secondary heat exchangers will be of conventional design, and the heat from the tertiary coolant will be disposed of in air blast coolers, located outside the containment. Natural circulation shut-down coolers will be located in a chimney stack.

The blowers, or circulators, are of the centrifugal type,

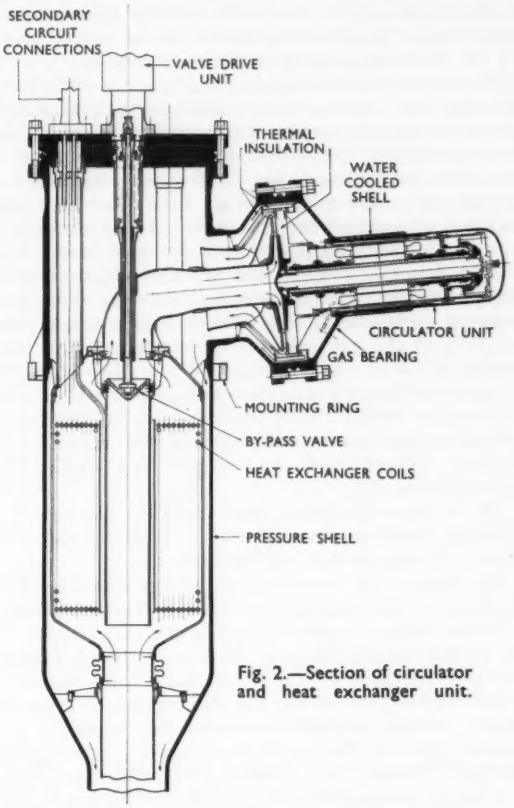


Fig. 2.—Section of circulator and heat exchanger unit.

each of which has a capacity of 3.71 lb/sec, with a pressure difference of 5 p.s.i., at the normal speed of 10,900 r.p.m., at which speed the estimated power is 75 h.p. The motors, of the 3-ph. squirrel-cage type, are capable of a maximum output of 100 h.p. at 12,000 r.p.m. Stepless speed variation to deal with varying reactor loads is provided by driving all six blower motors in parallel from a frequency-changer unit. Normally, the failure of one blower will shut down the reactor. Under shut-down conditions, it is stated that natural circulation will suffice. If, however, the reactor is shut down while all blowers are operative, the frequency changer would be run by a pony motor, at about 25% speed, from a guaranteed supply.

Gas bearings will be used on the blower motors to overcome the lubrication problem; a representative unit is now under development.

Charge Machine

Considerable effort was devoted, in the early stages of design, to deciding whether the charge machine should be an integral part of the reactor, or a separate removable unit. Taking into account the extra height involved with a removable machine, in addition to the extra weight of the machine (if separately shielded) and the necessity of depressurizing, of providing either a large seal or a multitude of small seals at inconveniently small centres, and the number of attachments and accessories required, it

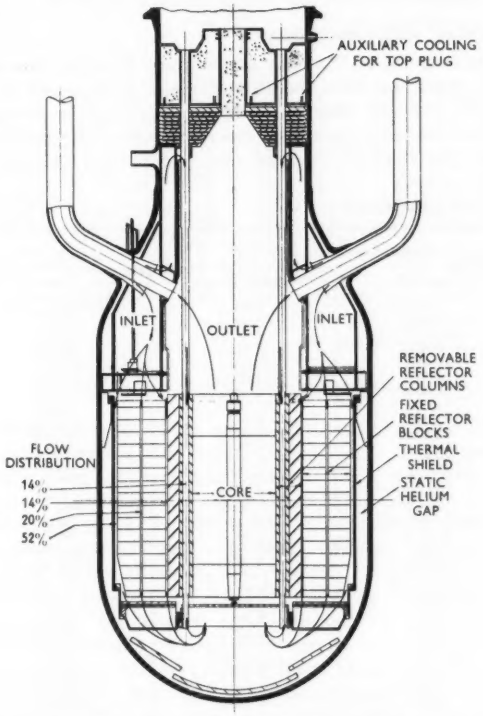


Fig. 1.—Section of reactor, showing coolant flow.

was considered preferable to make the machine an integral part of the reactor. The general design of the machine has now reached finality; some detail design is not yet complete.

The machine is housed in the upper neck of the vessel, above a water-cooled shield plug. Primary circuit gas, cooled to about 50°C, keeps the machine at a reasonable temperature; the gas then returns to the reactor circuit via the shield plug, which it assists in cooling.

The charge machine is able, by rotation and the normal swinging "jib" arrangement, to cover all the fuel elements, as well as the removable reflector units. In action, it is first necessary to shut down the reactor, and allow the shut-down heat to decay for 12-18 hours, after which the grapple can remove filler plugs from the shield plug, parking them within the enclosure. A fuel element can now be removed and placed on a prepared base. A can is then lowered, through the gas lock adjacent to the charge machine, over the element and base, thus giving complete containment. The canned element is now passed out through the gas lock, and is transferred, first into a receptacle where the can and base are soldered together by induction heating, and then to a second station where the outside of the can is washed down to remove any external contamination. The element now passes down a lift to a "roundabout" or turntable, for storage. (See pull-out drawing.)

All the above operations are carried out remotely, from a charge machine control room. Both television and optical viewing systems will assist in this.

The motors for operating the charge machine movements are located radially around the charge machine in a similar manner to the drives for the control rods, and are located outside the inner shielding. Double bulkhead seals are provided on the drive shafts from the motors to the machine; the motors are also enclosed in a gas-tight casing. If it is necessary to remove the casing for maintenance purposes, this can be done in safety by pressurizing the space between the two shaft glands with clean helium.

If major modifications are required to the reactor later, it is possible to disconnect the flange joint in the lower neck of the pressure vessel; the entire charge machine, and upper portion of the vessel, can be removed by means of the crane, to the storage and test area (see pull-out).

Fission Product Removal

The basic process of fission product disposal is to pass a certain proportion (5 litres/sec) of the coolant gas through the fuel elements, and to absorb the products in charcoal beds cooled by the evaporation of liquid nitrogen, which afterwards serves to provide inert atmosphere for the inner containment. The gas enters the element by a porous graphite plug at the top, and leaves at the bottom via the hollow spike on which the element rests.

The first step in the process is provided by the graphite boxes, previously mentioned, inside the fuel rods. These not only stabilize the size of the purge passage, they provide a hold-up of an hour or so for volatile products, and they prevent fragmentation particles from choking up the purge lines.

From each fuel element, purge pipes pass to individual restrictor-precooler units, which equalize and monitor the flow, and cool the gas to room temperature, after which the gas passes to groups of delay beds. These, which can be operated as two separate groups, to allow an experimental element to be dealt with quite separately from the main stream, consist of a number of charcoal-filled water-cooled U tubes (8-2 in., 4-4 in., 2-15 in.) for each unit. Six units are provided, but four are sufficient to give the desired delay (15 h for Kr and 200 h for Xe). From the delay beds, the gas passes to the purification plants.

Three purification plants enable independent operation of two, for experimental work, while the third is being regenerated. Each consists of three basic units; a freezer to remove CO_2 and H_2O, a charcoal trap cooled by liquid nitrogen to remove Xe and Kr, and a second trap to remove CO, N_2 and H_2. The gas leaving the third trap is used to cool the incoming gas to the freezer unit. It can then be transferred either back to the reactor circuit or to the dump tanks.

Arrangements are made so that any purification plant can receive gas from the dump tanks, if required.

Shielding and Containment

On account of the high temperature at which the pressure vessel operates, neutron damage is expected to be slight, and the thermal neutron shielding is arranged outside the vessel, alternate layers of steel and water being used; the thickness around the core portion being 8 in.

TABLE 2.—Estimated Activities in Reactor Circuit

Isotope	Half Life	Estimated normal activity level			
		Fuel Space	Purge Gas	Coolant Circuit	Trap
Ba 140 p	12.80 d	2.00 kc	1.00 c	1.000 c	1060 kc
Br 83 p	2.40 h	16.00 kc	7.60 c	5.000 c	65 kc
Cs 137 p*	30 y	0.04 c	2×10^{-5} c	2×10^{-5} c	21 kc
I 131 p	8.05 d	1.50 kc	0.70 c	0.700 c	488 kc
I 133 p	20.80 h	30.40 kc	14.40 c	13.700 c	1070 kc
I 135 p	6.68 h	81.40 kc	38.60 c	32.600 c	914 kc
Kr 83m d	114 m	3.80 kc	1.80 c	3.100 c	77 kc
Kr 85m p	4.36 h	30.00 kc	14.40 c	11.700 c	223 kc
Kr 85*	10.27 y	0.02 c	0.14×10^{-3} c	0.600 c	3.3 kc
Kr 88 p	2.77 h	110.00 kc	52.20 c	35.800 c	514 kc
Mo 99 p	67 h	9.00 kc	4.30 c	4.300 c	1020 kc
Rb 88 d	17.80 m	73.40 kc	35.00 c	35.700 c	514 kc
Sb 125 p*	2.20 y	2.20×10^{-3} c	1×10^{-5} c	1×10^{-5} c	880 c
Sb 127 p	93 h	267.00 c	0.13 c	0.100 c	42 kc
Sr 89 p	54 d	370.00 c	0.18 c	0.200 c	810 kc
Sr 90* p	28 y	0.06×10^{-3} c	0.03×10^{-3} c	0.03×10^{-3} c	25 kc
Sr 91 p	9.70 h	57.50 kc	27.30 c	24.300 c	940 kc
Sr 92 p	2.70 h	185.00 kc	88.00 c	60.000 c	845 kc
Tc 99m d	6.04 h	9.00 kc	4.30 c	3.700 c	1100 kc
Te 127m p	90 d	2.60 c	1.2×10^{-3} c	1.2×10^{-3} c	9.5 kc
Te 129m p	33 d	43.00 c	2×10^{-3} c	2×10^{-3} c	57 kc
Te 131m p	30 h	1.50 kc	0.70 c	0.007 c	73 kc
Te 132 p	77 h	5.70 kc	2.70 c	2.700 c	740 kc
Xe 133 d	5.27 d	142.00 c	0.07 c	0.200 c	1100 kc
Xe 135 d	9.13 h	8.00 kc	3.80 c	7.500 c	1040 kc
Y 90 d*	67.50 h	5.50×10^{-4} c	2.6×10^{-6} c	8.3×10^{-6} c	25 kc
Y 91 p	58 d	424.00 c	0.20 c	0.200 c	1000 kc
Y 93 p	10 h	61.60 kc	29.20 c	26.000 c	1030 kc
Zr 95 p	63 d	423.00 c	0.20 c	0.200 c	1080 kc

* Activity after 10^4 hours. p Parent. d Daughter.

Below the reactor, between the vessel and the bottom shield, is a graphite thermal column for the ion chambers. Beneath the reactor, the thermal shield is supported by high-density concrete, sufficient to enable access to be obtained to the underside of the reactor, when shut down. A mass concrete biological shield around the reactor will reduce the full-power radiation in the outer containment to less than 1 m.p.l.

As will be seen from the pull-out, double containment is provided. The inner shell, 66 ft diameter and approximately 80 ft high, is of steel, and is designed as a "hot" cell; access is only intended, when the reactor is shut down, for personnel wearing protective clothing and breathing apparatus. Designed to withstand an internal pressure of 10 p.s.i., the shell will normally operate at atmospheric pressure, with an inert atmosphere (nitrogen derived from the fission product cooling plant).

The outer shell, 110 ft diameter and something over 86 ft high, is of concrete, with walls 2 ft thick, designed for an internal pressure of 3 p.s.i. It will normally operate at atmospheric pressure, or very slightly below since, although it is a sealed building, it is intended for normal access, as required, although it is not expected that more than ten men will normally occupy it.

Ventilation

The inner containment is ventilated with nitrogen, the general scheme being as shown in Fig. 3. The nitrogen, either from the fission product cold traps, or from a storage tank direct, heated (if necessary) to an acceptable temperature, is supplied to the inner containment at a rate of approximately 2,000 ft³/h. Special valves are provided at inlet and exhaust, which will automatically close and seal the inner containment if the activity exceeds permissible levels. The nitrogen is cooled, filtered, and discharged to the main stack.

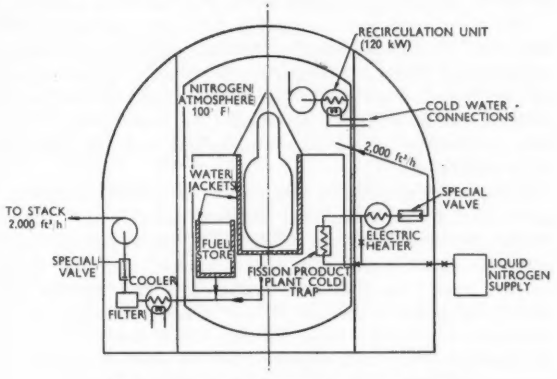


Fig. 3.—Diagram of inner shell ventilation.

Water is used as the main heat sink for most of the reactor plant (i.e., the thermal shield, etc.). It is expected that the nitrogen will take up about 120 kW of heat, and this is removed by water-cooled recirculation units.

Ventilating air for the outer containment is normally by conventional fans and filters, through heaters and coolers, the air intake being some 750,000 ft³/h. In addition, heater/cooler recirculator units are fitted. In emergency, the normal ventilating air is stopped, the building sealed by valves, and special recirculator units, incorporating fission product traps, draw air from the space between inner and outer containment, filter it, and discharge it into the outer containment, thus cutting down possible leakage of fission products between the two shells.

Auxiliary Buildings and Supplies

The general site layout is shown in the pull-out drawing. The main building, or control block, is connected with the reactor at first-floor level by an enclosed walkway; the ground floor, as well as providing entrance hall and reception rooms, is devoted to cabling, air-conditioning and ventilation plant; offices are on the second floor. Nearby is the service building, containing power transformers, electrical machinery and boiler plant.

The active storage building, connected with the reactor by a covered passage and vehicle airlock, not only provides storage for new and irradiated fuel elements, but forms a parking area for vehicles and shielded trolleys, and facilities for washing-down slightly active components, change rooms, and chemical laboratory.

Adjacent to the 60 ft stack is the housing for the main coolers and associated pumps, nitrogen plant, etc.

Water supplies are of two types; demineralized, for cooling important features such as the charge machine, the fission product plant and the thermal shielding; for other

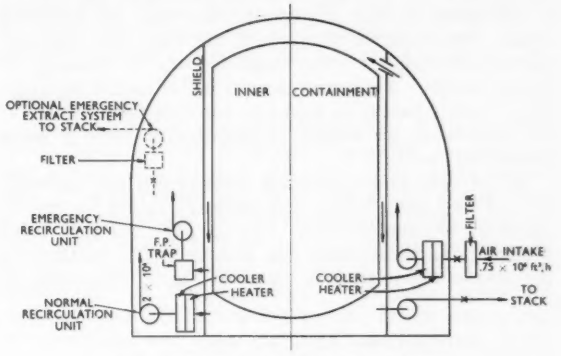


Fig. 4.—Diagram of outer shell ventilation.

purposes, process water is used. Gravity tanks are provided to cover interruptions of supply.

The main electrical supply will, it is estimated, not exceed some 2,000 kVA. Guaranteed supplies, by means of diesel sets and batteries, are provided for the essential services, such as the main gas blowers (25% speed); fission product plant circulators; instrumentation and control valves, emergency lighting, etc.

Progress

Construction of DRAGON, as would be expected, is not very far advanced but a contract has been placed with Turriff Construction Corporation, Ltd., London, S.E.1, for opening up the site, i.e., excavation and construction of foundations and provision of temporary services. Transportation, erection, operation and dismantling of temporary cranes is being carried out by Constructors John Brown, Ltd. The pressure vessel contract has been placed with Mannesmann-Export, Düsseldorf, and Head Wrightson (Teesdale), Ltd., are providing the thermal shield.

A considerable amount of experimental work on details must of course be undertaken before the reactor is built and C. A. Parsons and Co., Ltd., have a contract for a high-temperature experimental plant for seven fuel elements, while de Havilland Engine Co., Ltd., are building five in-pile assemblies which will be tested in PLUTO. Development of impregnated graphite is under way at Hawker-Siddeley Nuclear Power Co., Ltd., while studies of carbide/oxide systems and graphite impregnation are being undertaken by the Royal Aircraft Establishment, Farnborough. Criticality of DRAGON is expected in 1963.

DRAGON Control System

By J. R. DEAN, B.Sc.(Eng.), A.M.I.Mech.E., A.M.I.E.E.
(Senior Engineer, Control Engineering Section, OEEC High Temperature Reactor Project, AEE, Winfrith)

THE control system now being developed for DRAGON provides for 24 absorber rods containing boron-carbide granules to be lowered into holes in the reflector near the edge of the core. With all rods lowered, a virtually solid curtain is formed and all neutrons leaving the core are lost.

Calculations and experiments on the zero energy reactor ZENITH indicate that the system will need to control a reactivity of about 14%, composed of 5% for temperature changes, 6% for fuel depletion and poisoning, and 3% for a shut-down margin. It is estimated that the proposed system will suppress 17%, with the value of each rod varying between 0.5-1.0%, depending on the shading of others nearby. A number of rods will therefore be available as safety rods to be held out ready for fast insertion at all times when the reactor is operating or work is being carried out on it.

All 24 rods and their drive mechanisms are identical. In plan they are arranged symmetrically round the reactor centre at 30 equal intervals with six gaps, the gaps being available for instruments and sources. The location of the various major parts is shown in Fig. 1. The rods are seen suspended on stainless steel wire cords which pass through the hot (750°C) gas in the plenum chamber above the core. Each cord is protected by a set of concentric tubes, the inner one of stainless steel and the outer ones of Nimonic. A small flow of cooling gas at 350°C enters the tubes at the top, flows over the cord and absorber rod and leaves at the bottom of the hole in the reflector. By this means the temperature of the cord will be kept down to 400°C, so that its strength will not be seriously impaired.

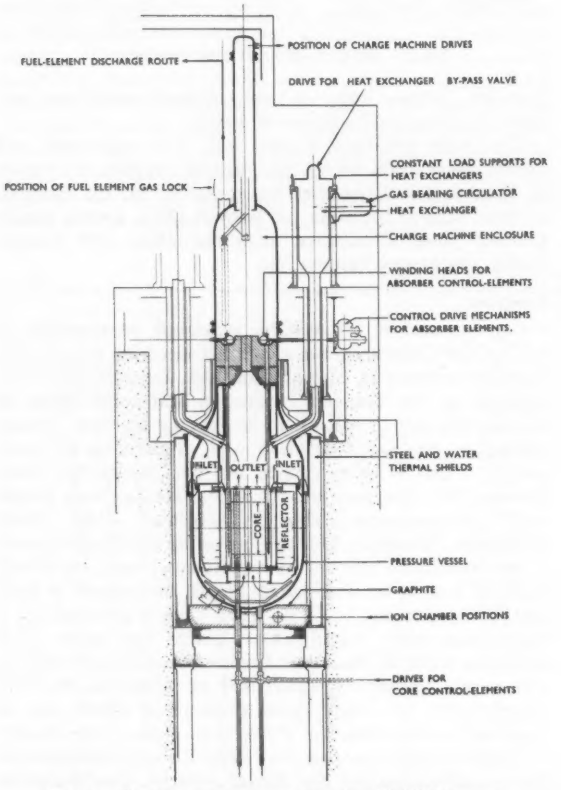


Fig. 1.—Control arrangement for the DRAGON core.

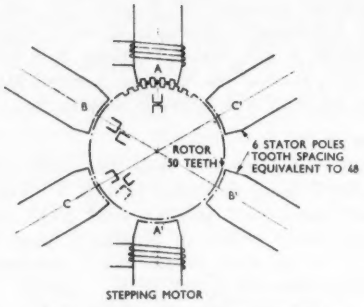


Fig. 2.—Principle of operation of stepping motor.

The wire cord passes round a 2 in. dia. pulley on the absorber rod and the upper ends wind onto two symmetrical grooved pulleys so that the rod remains in the centre of the tube. The pulleys are bevel gear driven in a winding head, which is attached to a stem fitting in a hole in the top shield plug and simply rests in position on a conical seat.

Each winding head is coupled by a splined transverse shaft, 8 ft 6½ in. long, to a gearbox carrying the motor, housed in a small pressure vessel. The shafts pass through pressure tubes connecting these vessels and the main reactor vessel, so that the mechanisms and motors are wholly enclosed in helium at the reactor pressure of 20 atmospheres. In this way, the only vessel penetrations are for electric cables, and running seals are avoided. It would be very difficult to develop a running seal to hold helium to the high standard demanded.

The gearbox provides a speed reduction of 6 : 1 from the motor: it also transfers the energy from the absorber rod into a flywheel when the rod is released to fall under gravity, as it is when a fast insertion speed is required. The flywheel runs on through a free-wheel at the end of the fall and is slowed down eventually by incidental friction. The gearbox also contains the mechanical end stops, the limit switches and the transmitter synchro to indicate position.

The switches and synchro are associated with the mechanism rather than the absorber rod because they are needed to control the mechanism movement. A precise knowledge of the reactivity suppressed by a rod cannot, in any case, be deduced from position, so that variations

due to cable stretch are not important. The ability to move a rod back accurately to a position recently vacated may well be of importance and the synchro system, in which a servo motor drives a display unit and brings a follower synchro into agreement with the transmitter, is expected to give accuracies of about 1/2,500 of the total stroke.

The motor is a "stepping" motor which will run in either direction at a chosen speed, can lock magnetically in any position, or can be released to run free and allow the absorber rod to fall. Lack of supply gives the free condition.

The individual units making up the control system are described in greater detail below.

Stepping Motor

The stepping motor, manufactured by Sperry Gyroscope, is a development of the light-load follower motors used in compass systems. Fig. 2 illustrates the principle of operation. The six salient stator poles are energized in opposite pairs successively, AA, BB, CC, so that the magnetic field moves in increments of 120°. The poles have teeth with spacing equivalent to 48 teeth on a complete circle. The rotor, of laminated iron, has 50 teeth on its circumference. The teeth are consequently opposite each other at one pair of poles and misplaced by $\frac{1}{3}$ or $\frac{2}{3}$ of a pitch at the others. When there is a change in excitation the teeth in the magnetic field attempt to align; if the load torque is not too great the rotor will rotate

$$2.4° = \left(\frac{360°}{3 \times 50} \right)$$

The sequence ABC gives one direction of rotation, ACB the opposite. Energizing only one pair of windings locks the rotor magnetically and complete de-energization allows it to run free. The simple A, B, C sequence passes through a de-energized state at each change, so an alternative will be used, either AB, B, BC, C, CA . . . or AB, BC, CA. . . .

A pulse triggered transistor circuit will probably be used for sequencing, in which case the AB, BC, CA . . . sequence will be used, having only three steady states. With the six-state sequence, the magnetic steps are smaller and so the running is smoother and the torque higher. This could easily be obtained from a motor-driven commutator.

With a three-state circuit, the absorber rod operating stroke of 78 in. will be covered in 3,190 steps of 0.0245 in., each representing a maximum possible reactivity increment of 0.616×10^{-5}, i.e., when the rod is in its most effective position and unshaded.

The shortage of physics data affecting control has led to the choice of a system allowing flexibility in the method of operation and subsequent changes to be made with ease. The identity of the absorber rods and their symmetrical array help in this. A single average speed has been chosen for the motor, depending on the stepping frequency: only the electric circuits outside the reactor need to be changed if a different or more speeds are needed later.

The stepping principle has, of course, been applied in moving a rod linearly. The compact rotary form is more convenient in the DRAGON system where long inflexible rods would be difficult to accommodate.

The stepping motor has other features with a bearing on safe operation. It cannot lift more than 50% overload. Consequently, if friction builds up to this value due to deterioration of the mechanism, the failure to wind up will be apparent when the frictional resistance is still small enough to be overcome by the rod weight. Secondly, if the rod meets a solid obstruction the motor slips, and the load is released because the teeth cannot catch the moving load. This overload limit is particularly valuable in a helium atmosphere where rubbing friction surfaces would quickly be destroyed. Thirdly, there is a maximum pulse frequency which a motor and its load can follow, i.e., a maximum speed for the system. This is dependent on load torque and inertia. The greater the inertia the longer is the interval needed for the rotor to move into position for the next pulse: failure of the rotor to arrive in time results in progressively reduced torque so that the load again runs free.

Tests on an experimental motor confirm that the available load torque is reduced when load inertia is increased. The reduction was less pronounced and vibration of the system was reduced by putting a rubber coupling between the motor and the input pinion.

The apparent delay times in releasing loads from the magnetically locked condition have been measured and found to compare well with orthodox magnetic clutches. The apparent delay, made up of a real delay and the braking effect of the dying magnetic field, becomes less as the load torque approaches the breakaway torque. It is about 10 milliseconds when the ratio of torques is 0.75.

Gearbox

The gearbox is shown diagrammatically in Fig. 3. The motor input at shaft A drives through an intermediate gear integral with shaft B and from there to the output shaft C. The output shaft is surrounded by a re-entrant sleeve which retains oil in the gearbox to lubricate the gears and the bottom bearings. The upper bearings will be grease-packed. Geared to shaft B is shaft E, which rotates 311° for full rod travel. This shaft carries the position transmitter synchro, the limit switch striker and the mechanical end stops, the crash stop supplying spring cushioning when the rod reaches its lower limit. A system

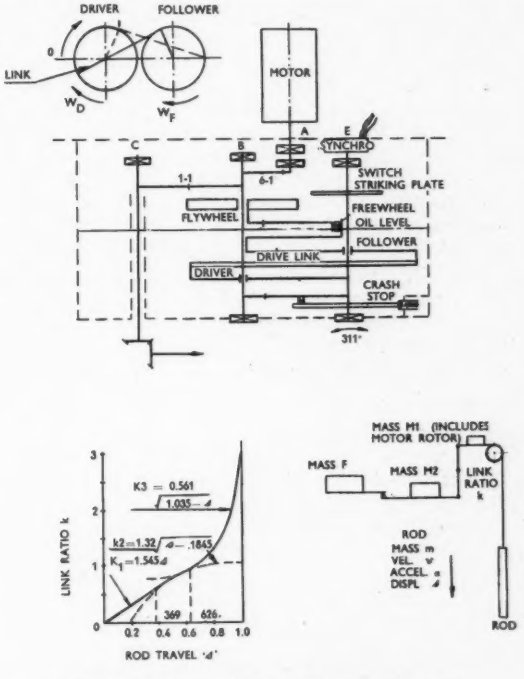


Fig. 3.—Gearbox (above) in diagrammatic form; (below) a simple kinetic analogue.

of gears, free running on shafts B and E, terminates in a flywheel which is driven through a free-wheel. Before the free-wheel there is a link (illustrated separately in Fig. 3) between two gears, the driver and the follower, which changes the velocity ratio, ω_F/ω_D, from 0 to 3 as it moves from the position shown full to that shown dotted.

When the motor is switched off, the absorber rod falls and drives the mechanism so that the flywheel is accelerated at a rate depending on the link velocity ratio, k. The mechanism is finally brought to rest by the crash stop and the flywheel runs on. The stop is reached 2½% before the end of maximum travel (when the drop is from the top) and at this point about 95% of the energy of the system is in the flywheel.

A simple kinetic analogue of the mechanism is shown in Fig. 3 where the inertias of the rotary masses are replaced by masses which move linearly. Knowing k as a function of displacement s, theoretical performance curves can be

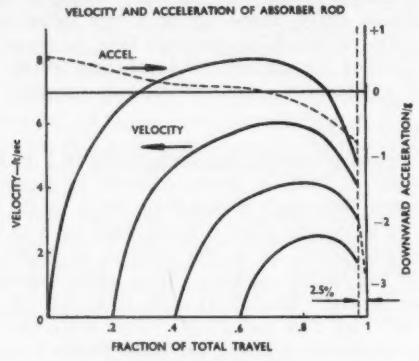


Fig. 4.—Velocity/displacement for total and partial stroke of control rod.

calculated if a mechanical efficiency is assumed. The function and its integral and derivatives may be obtained graphically. A direct analytical solution has proven impracticable, but a method of finding expressions of near fit for a graphically determined curve has given the results shown in Fig. 3. These expressions were used, with an assumed 60% efficiency, to obtain the velocity-displacement curves for total and partial stroke, shown in Fig. 4.

The effectiveness of a control rod along its stroke is expected to be approximately as shown in Fig. 5A. Combining this with the free-fall performance, the curves shown in Fig. 5B are obtained, giving the reactivity suppressed by a falling rod plotted against time, expressed as a fraction of the reactivity suppressed by the rod when it is fully inserted. The reactivity suppressed by a fully inserted rod depends on many factors such as shading and flux distribution.

Maintenance

As the mechanisms will be enclosed in pressure vessels directly communicating with the main reactor vessel containing contaminated helium, care has been taken to provide for easy removal and remote replacement if necessary. The mechanisms are divided into units which can be removed complete when faulty or exhausted, sealed, and taken to a handling cell, and replaced by identical, dimensionally controlled spare units which will fit any of the 24 sets. Each unit is self-contained and will be fully adjusted and tested before installation. The removal and replacement procedure can be followed in Fig. 6 which is a schematic diagram of the mechanism.

The motor drive to the rod, through the transverse shaft and winding head, passes through a differential gear train in the overwind mechanism. When the reactor pressure has been lowered so that the pressure cap can be removed, the control rod can be lifted an additional 91 in. by attaching a handle on the shaft at A and hand-winding through what is normally the reaction gear. The hand-drive passes through a bellows-sealed unit, B, which prevents the escape of contamination. A spring loaded stop system, C, limits the hand-winding and carries switches which at one extreme indicate that the rod is fully raised and at the other extreme that the full reaction load of the rod's weight is being carried by the reaction gear.

When the rod has been raised sufficiently, the hand-drive can be withdrawn 2 in. by a screw, shown at D, operated by attaching a second handle. A push rod and the transverse shaft are then urged by a spring so that the shaft is withdrawn from splined engagement with the winding head, and a spring-loaded dog in the head engages to prevent the rod from falling. A seal between the shaft and the surrounding pressure tube is closed by the movement of the shaft. Leakage between the surfaces which slide during the shaft withdrawal is prevented by a second set of bellows at E. At its uppermost position the rod is steadied in a hole in the stem of the winding head. The overall length of head and rod is such that the whole assembly can be lifted off its seat by the fuel handling machine and then sealed and transported in the same way as a fuel element.

Because the mechanism vessel is now isolated from the main vessel, it can be purged clean and the top pressure cap removed, carrying with it the spring-loaded plungers which hold the gearbox in position. The gearbox and its motor can be lifted out, breaking a series of plug connections, F, on the support ring, and withdrawing the splined output shaft from the overwind mechanism. The overwind mechanism can now also be removed from the vessel: it is designed to pass freely through the flange-connection.

The mechanism can be removed by the method described above even if it can be operated over only part of the stroke, or none at all. Provision is made, in this case, to ensure matching of the splined connections to give the correct relative positions on reassembly.

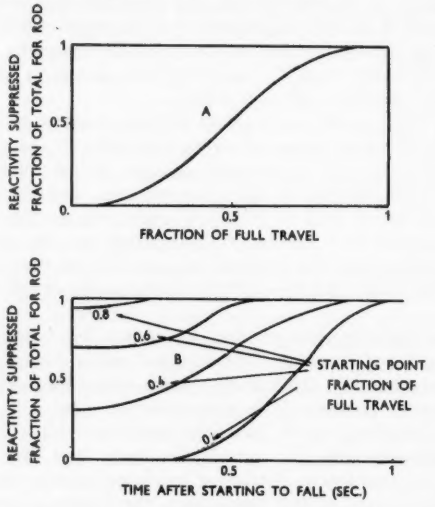


Fig. 5.—Control rod effectiveness in suppressing reactivity.

The World's Reactors

No. 26 DRAGON

OWNER: O.E.E.C. High Temperature Reactor Project (DRAGON)

LOCATION: Winfrith, Dorset.

TYPE: Thermal, homogeneous.

PURPOSE: Experimental.

CAPACITY: 20 MW thermal.

FUEL AND MODERATOR: Enriched uranium and thorium carbide sintered ring-type inserts, 1.428 in. (36.2 mm) o.d., and 0.26 in. (6.55 mm) radial thickness × 0.95 in. (24.12 mm) long; arranged around graphite spine in graphite fuel boxes (6 inserts per box). Combined containment and moderation is provided by hollow graphite fuel rods (10 boxes per rod). Each fuel element consists of a hexagonal cluster of 7 rods, at 2.5 in. (63 mm) centres, the overall length (including end reflectors) being 100 in. (254 cm) and the active length 63 in. (160 cm).

CORE: 37 fuel elements at 6.615 in. (16.8 cm) triangular pitch, surrounded by movable and fixed annular graphite reflectors.
Equivalent diameter of core: 42.25 in. (107 cm).
Outside diameter of movable reflector: 66 in. (167.6 cm).
Outside diameter of fixed reflector: 116.625 in. (296 cm).
Voidages: Core coolant 13.1% total core voidage, 15.5/16.0%; end reflector 20%; radial reflector 5.73%.
Total loading: U^{235} 20 kg; Th^{232} 134.8 kg.
Graphite/U^{235} ratio (ats.): 2128.
Th^{232}/U^{235} ratio (ats.): 6.83.
Initial conversion factor: 0.52.
Initial flux: 4.5×10^{13} n/cm², sec.

TEMPERATURE COEFFICIENTS: Fuel (at 1,300°K): -0.7×10^{-5}/°C.
Moderator (at 1,200°K): -4.5×10^{-5}/°C.
Side reflector (at 700°K): $+2.5 \times 10^{-5}$/°C.
End reflector (at 1,100°K): $+0.1 \times 10^{-5}$/°C.
End reflector (at 700°K): $+0.2 \times 10^{-5}$/°C.

CONTROL: 24 rods on pitch circle 48.5 in. (123 cm) diameter. Stainless steel sheaths 2.5 in. (63.5 mm) o.d., 1.62 in. (41.1 mm) i.d., and 5 ft (152.4 cm) long, packed with boron carbide.
Maximum withdrawal rate: 0.611 in./sec (15.5 mm/sec).
Time of fall: 1.2 sec.

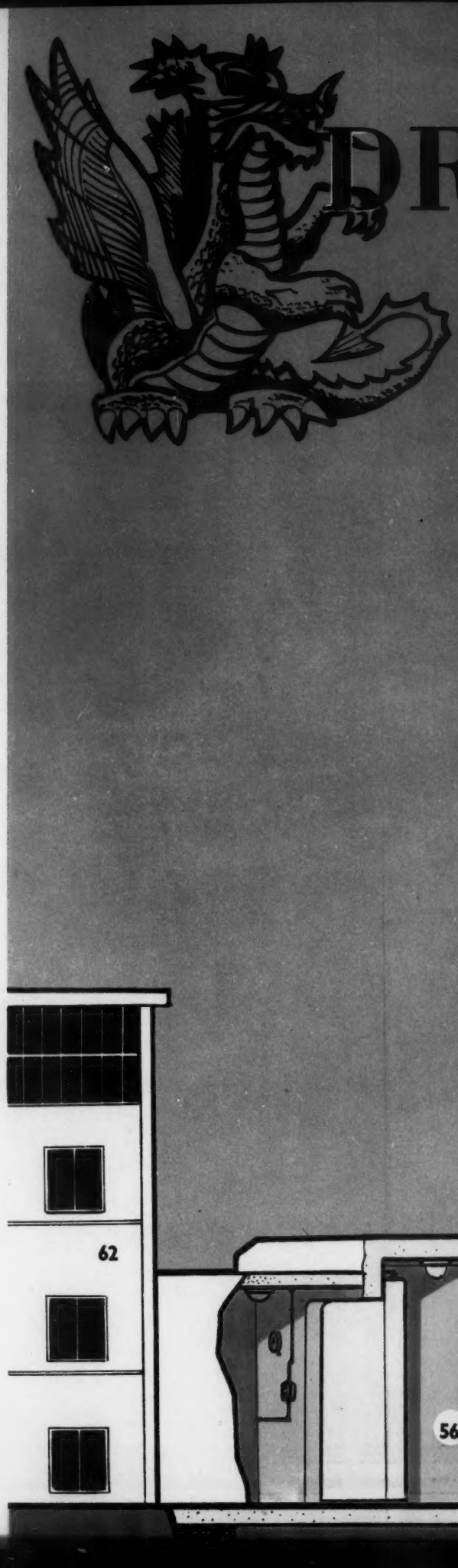
COOLANT: Helium at 20 ats. primary coolant, with water as secondary and tertiary coolant.
Inlet temperature: 350°C.
Outlet temperature: 750°C (926°C from hottest channel).
Total area of coolant passages in core: 1,271 cm² (196.8 in.²).
Mass flow: 9,618 g/sec (76.4 lb/h).

BLOWERS: 6 in parallel. Pressure drop: 5 p.s.i.
Maximum speed: 12,000 r.p.m.
Normal speed: 10,900 r.p.m.
Variable-frequency squirrel-cage motors rated 100 h.p. at 12,000 r.p.m.

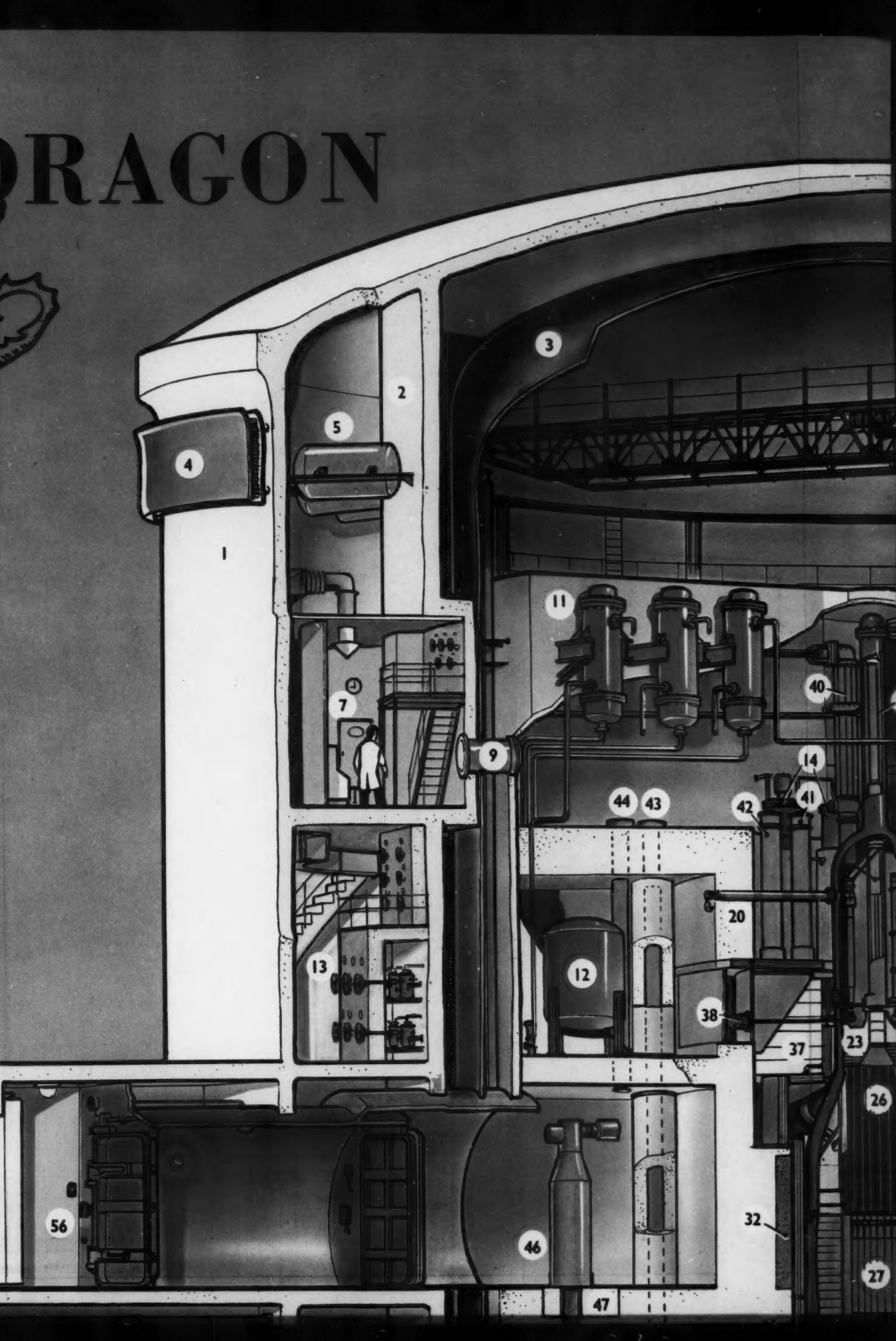
PRESSURE VESSEL: Overall height: 58 ft 1 in. (17.7 m).
External diameter over core: 11 ft 6 in. (3.5 m).
Internal diameter of lower neck: 6 ft 3 in. (1.9 m).
Internal diameter of upper neck: 2 ft (0.61 m).
Plate thickness; main vessel: 2.25 in. (57.2 mm); lower neck: 1.5 in. (38.1 mm); upper neck: 0.625 in. (15.9 mm).
Weight: 45.8 tons (45,533 kg).

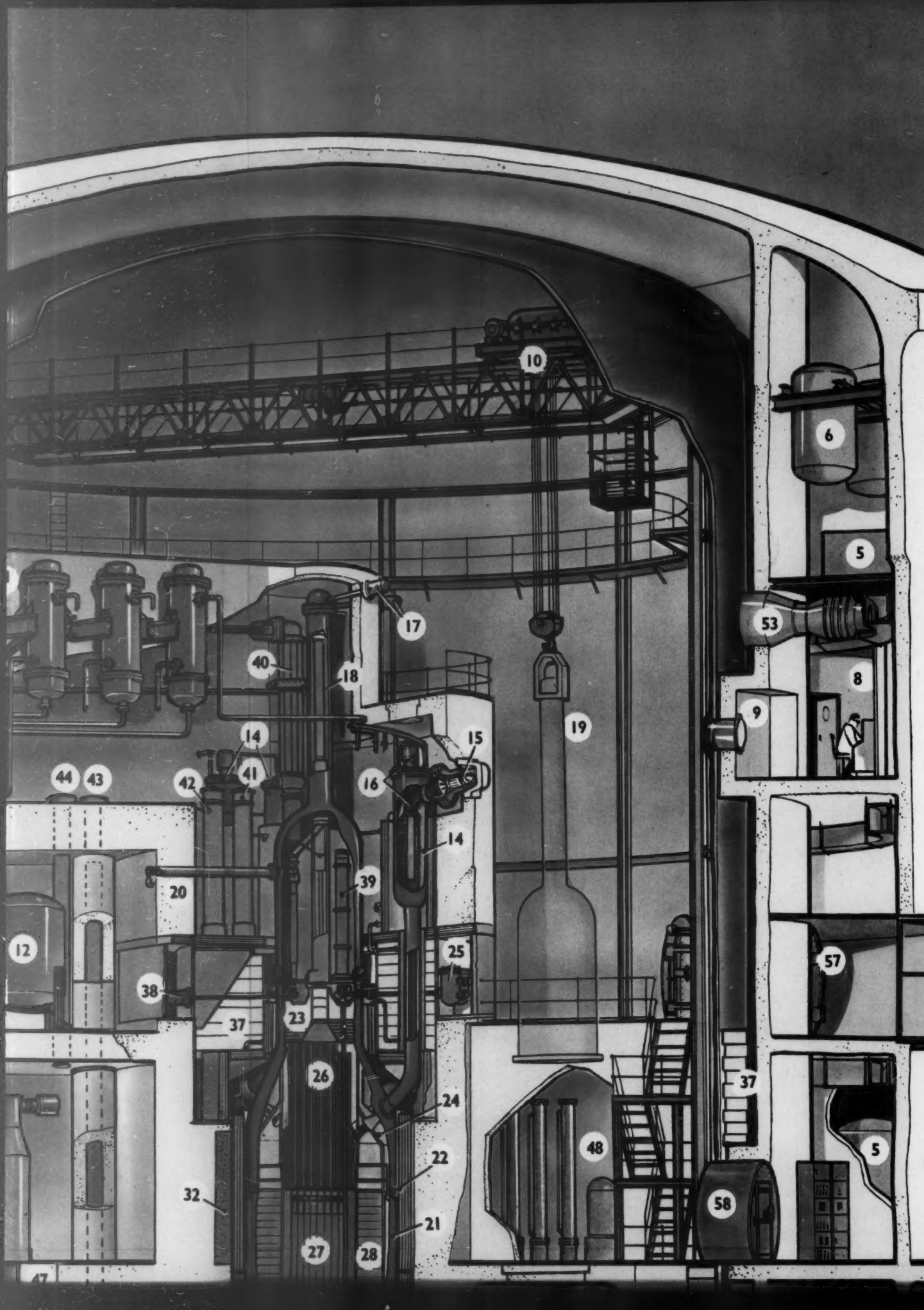
SHIELDING: 1 in. thick thermal shield inside pressure vessel. External shielding composed of alternate layers of steel and water 1 in. thick, the total thickness around main portion of pressure vessel is 8 in. steel and 7 in. water, with 5 ft 9 in. (1.753 m) concrete.

CONTAINMENT: Inner shell: 66 ft (20.2 m) i.d. × 80 ft (24.4 m) high, designed to withstand 10 p.s.i. internal pressure.
Outer shell: 110 ft (33.4 m) o.d. × 86 ft (25.2 m) high, designed to withstand 3 p.s.i. internal pressure.



RAGON

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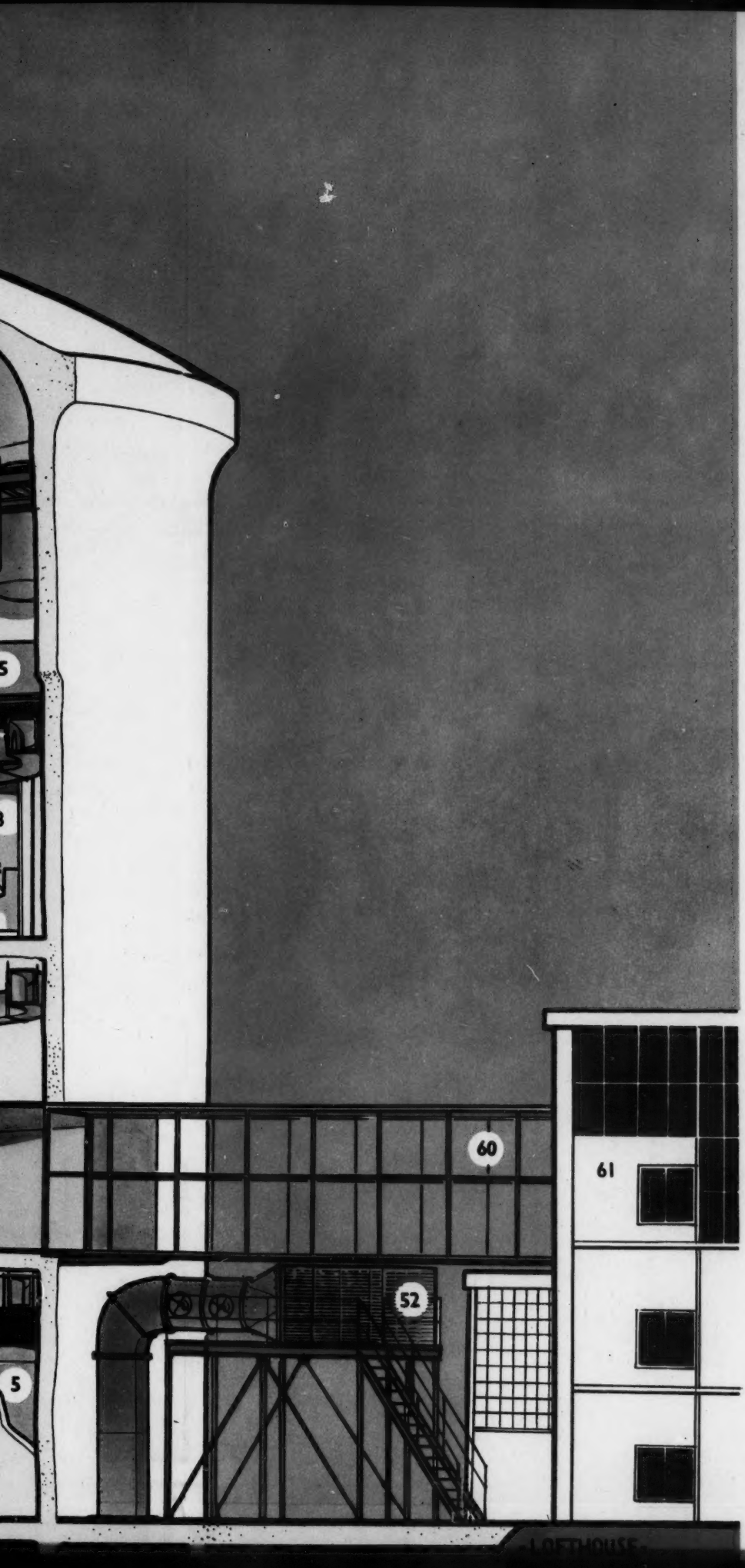


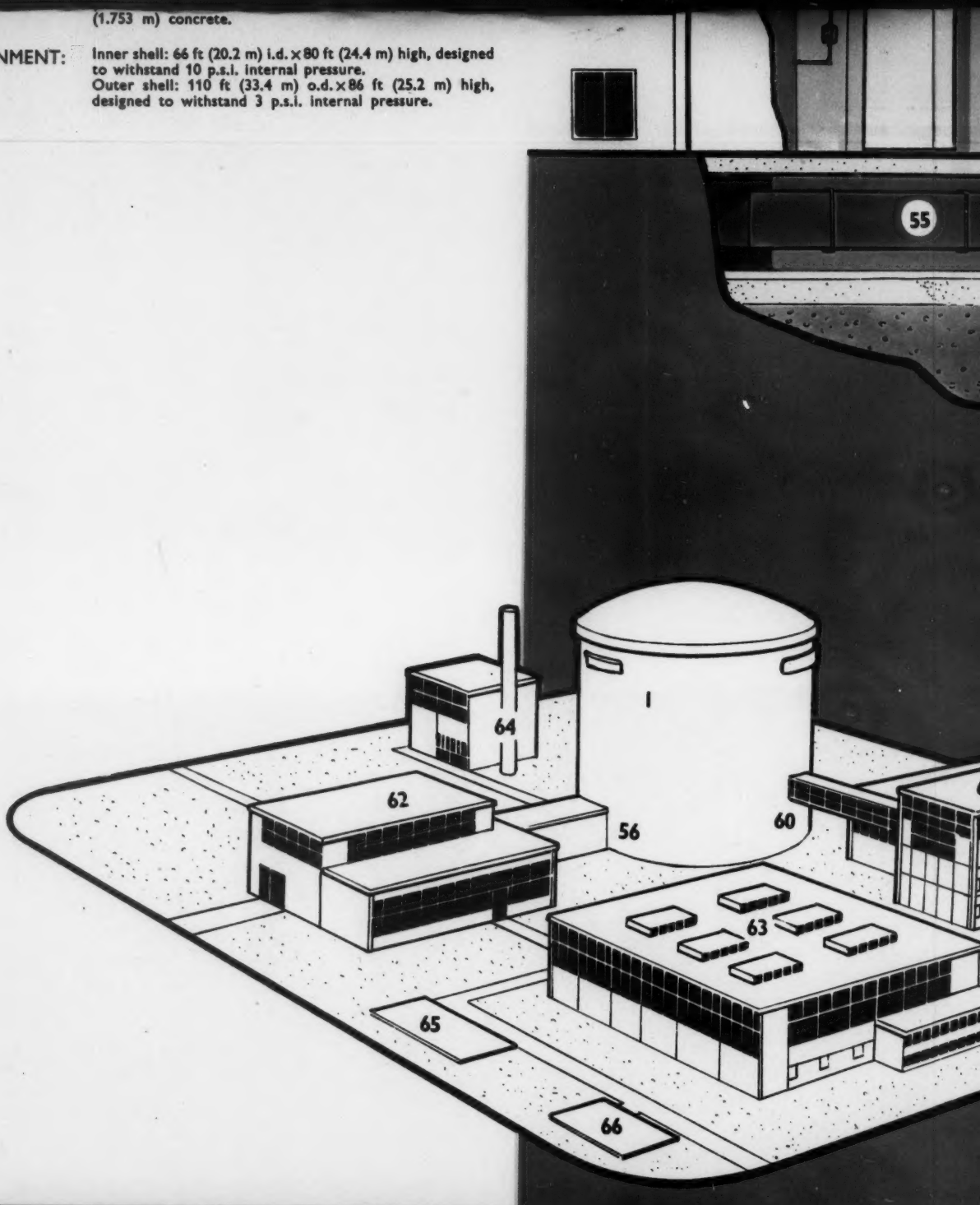
DRAGON REACTOR

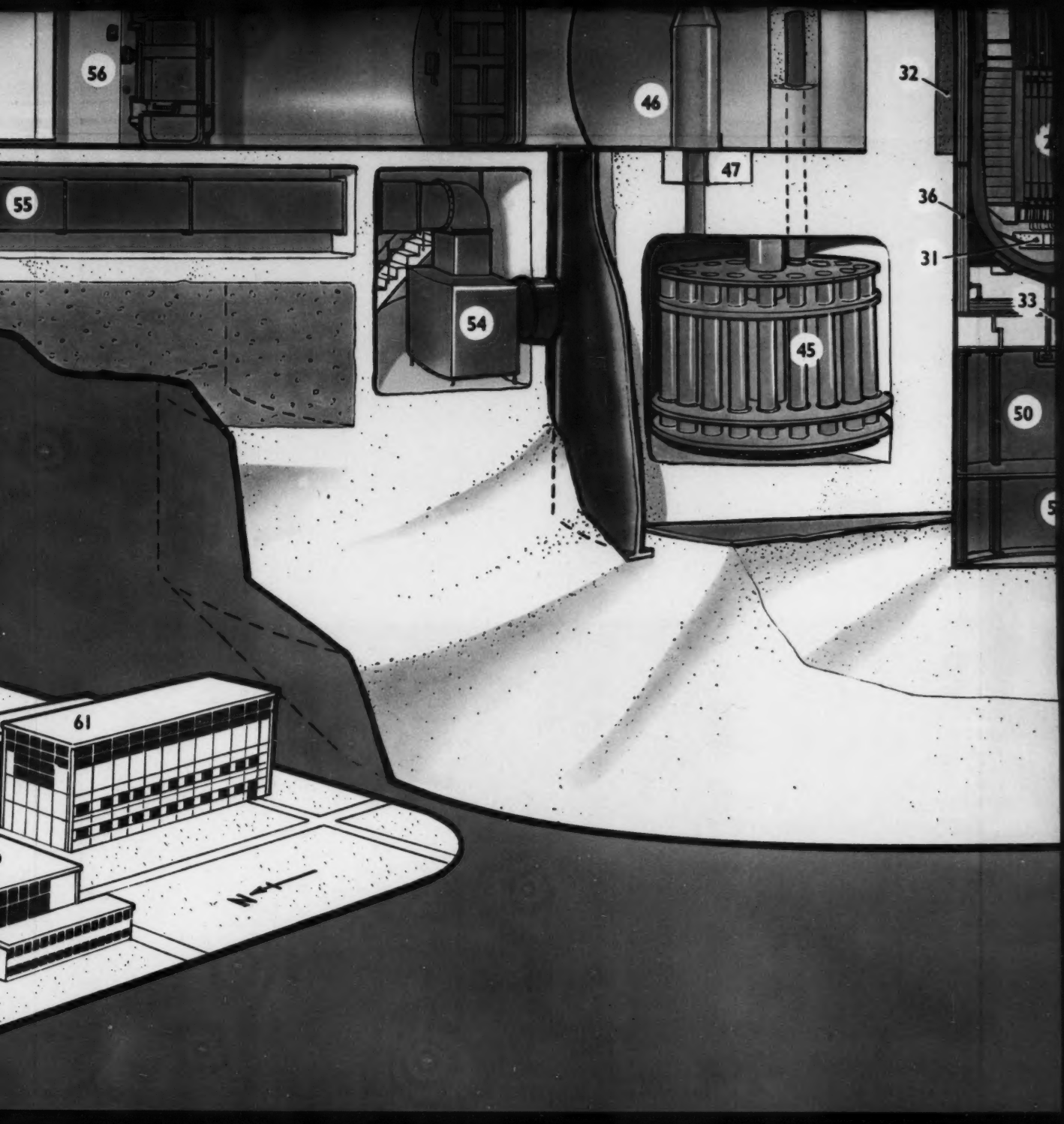
KEY

1. Outer concrete containment
2. Inner concrete wall
3. Inner containment steel shell
4. Shut-down coolers
5. Water storage tanks
6. Nitrogen storage tanks
7. Charge machine control room
8. Crane control room
9. Observation window
10. 25-ton rotating crane
11. Secondary heat exchangers
12. Secondary coolant dump tank
13. Secondary coolant control valves
14. Primary heat exchangers
15. Primary circulator
16. By-pass valve and drive
17. Charge machine drives
18. Charge machine
19. Charge machine in test area. (Available for storage during major modifications)
20. Charge machine viewing facility
21. Main pressure vessel
22. Main pressure vessel support skirt
23. Main shield plugs
24. Structural steel forming outlet plenum (and duct to control rods)
25. Absorber rod drive
26. Absorber rods
27. Core
28. Reflector
29. Core bedplate
30. Fission product pipes
31. Bottom neutron shield
32. Side neutron shield
33. Reserve control branches
34. Ion chambers
35. Bottom biological shield
36. Iron-water thermal shield
37. Loose shield blocks
38. Charge machine storage turntable drive
39. Storage can on c.m. turntable
40. Load facility transfer flask
41. Canning induction furnace
42. Can washing tank
43. Fuel element discharge chute
44. Fuel element charge chute
45. Fuel element storage roundabout
46. Transit flask
47. Eccentric plug
48. Fission product removal plant
49. Helium dump tanks
50. Reactor pit area
51. Support columns
52. Main ventilation inlet and filters
53. Circulating ventilation plant
54. Ventilation exhaust filters
55. Ventilation exhaust to stack
56. Vehicle airlock entrance
57. Personnel airlock access
58. Emergency personnel airlock access
59. Electrical supplies
60. Personnel walkway
61. Control block
62. Active storage block
63. Services block
64. Cooler block and stack
65. Delay tanks
66. Fuel oil storage tanks
67. Helium make up
68. Heat sink
69. Helium supply and purification plant
70. Liquid nitrogen supply
71. Nitrogen cooler and filter
72. Nitrogen recirculator and cooler

(1.753 m) concrete.

CONTAINMENT: Inner shell: 66 ft (20.2 m) i.d. × 80 ft (24.4 m) high, designed to withstand 10 p.s.i. internal pressure.
Outer shell: 110 ft (33.4 m) o.d. × 86 ft (25.2 m) high, designed to withstand 3 p.s.i. internal pressure.

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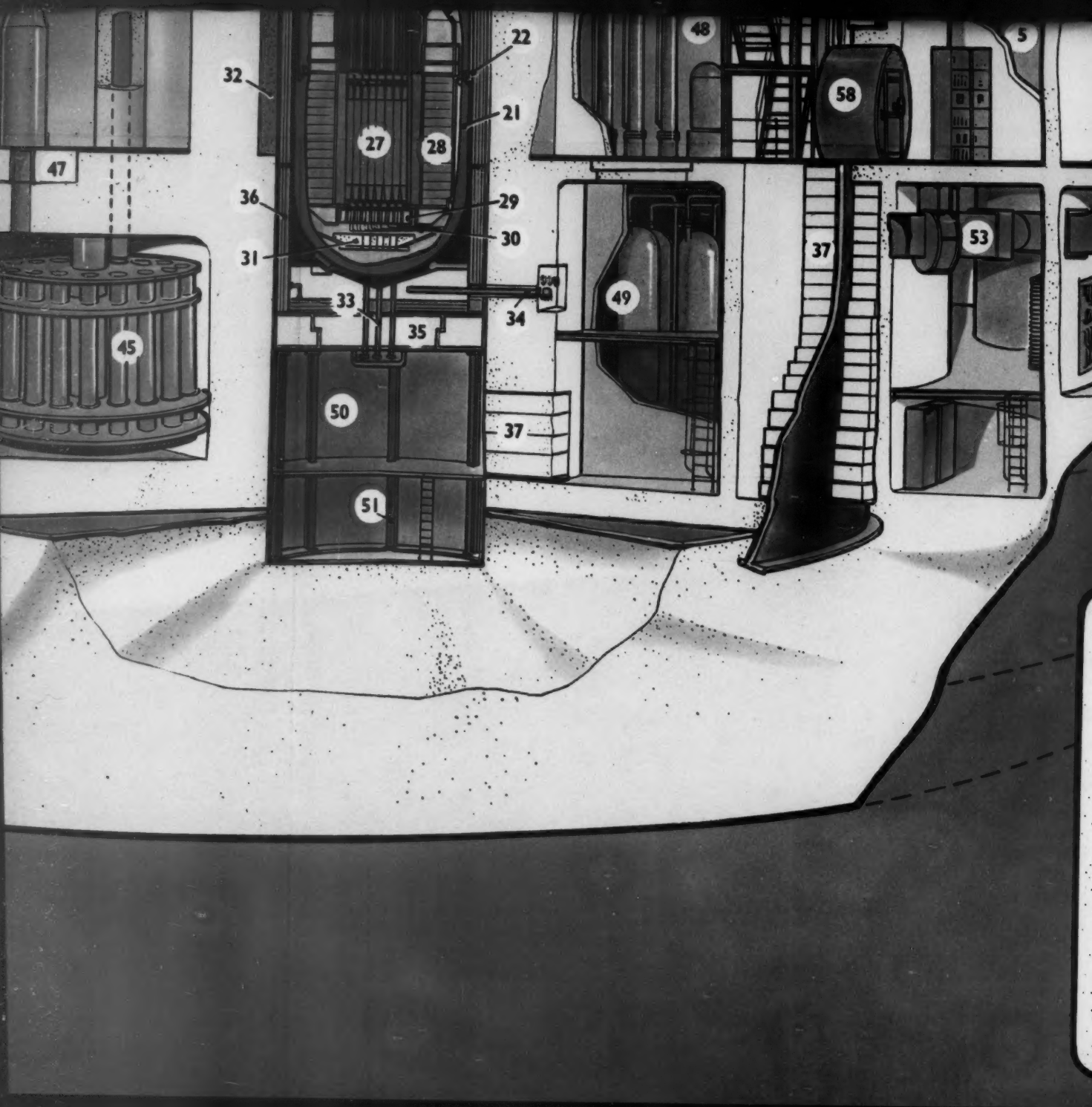
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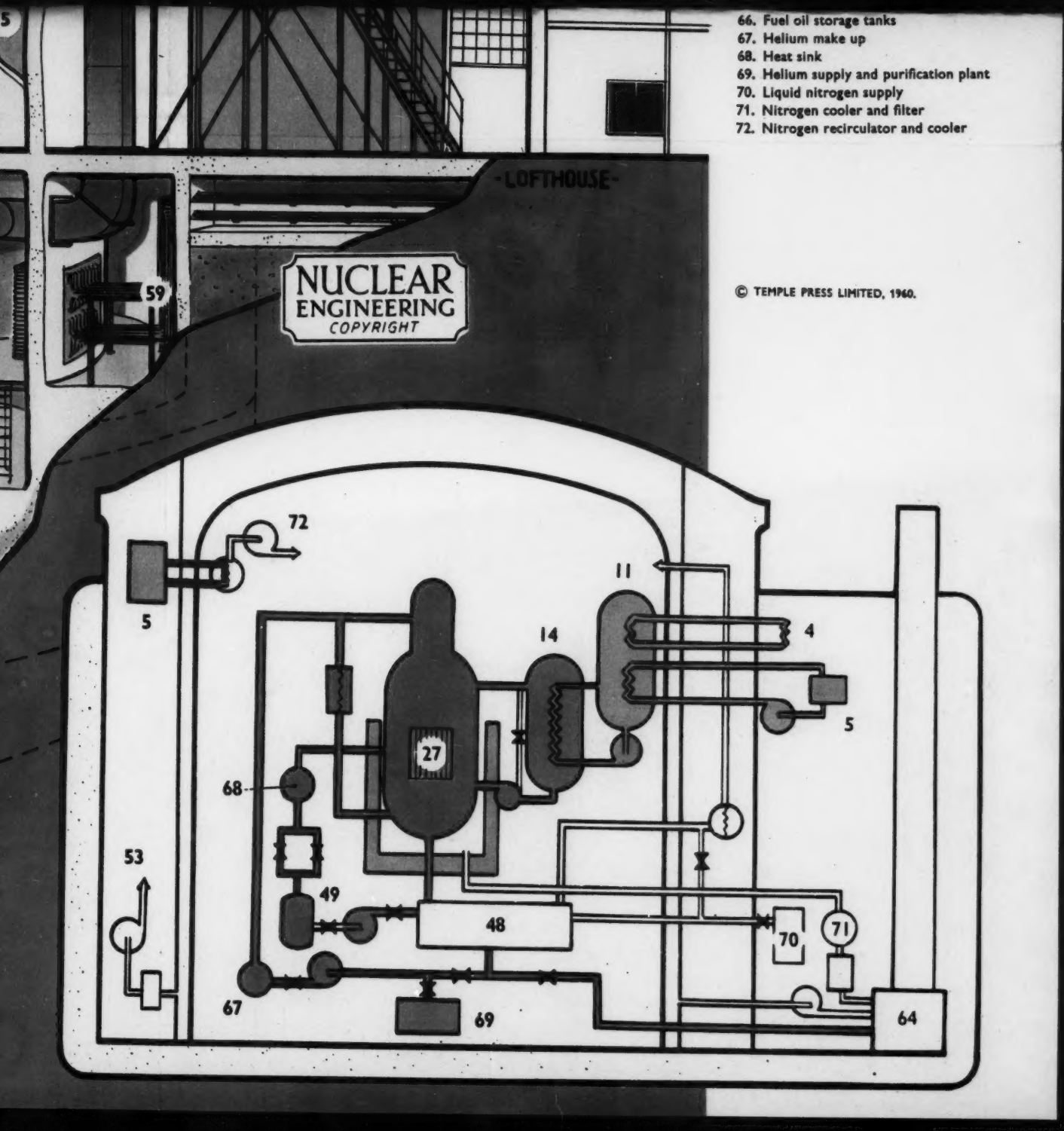

66. Fuel oil storage tanks
67. Helium make up
68. Heat sink
69. Helium supply and purification plant
70. Liquid nitrogen supply
71. Nitrogen cooler and filter
72. Nitrogen recirculator and cooler

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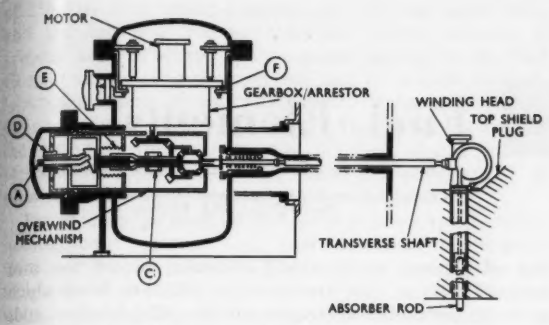

Fig. 6.—Schematic of absorber control system.

Design

The policy throughout has been to design mechanisms very robust for their duties and well lubricated, so that a long life and great reliability can be expected. With the exception of the absorber rods and the wire cords, the equipment is in regions of low radiation and low temperature. This permits the use of lubricants, such as the oil in the gearbox and grease-packing of the bearings in the winding head and overwind mechanism. It also means that well-tried engineering techniques can be used without recourse to exotic materials. The winding heads will be kept cool by the small current of cooled helium flowing down from the top of the vessel over the fuel-handling machine and through the main shield plug.

Because the mechanisms will operate in very pure helium, virtually devoid of oxygen, the protection against cold welding and pick-up, which the oxide film normally gives to rubbing metal surfaces, will not be present. The shortage of information on the behaviour of bearings and lubricants in these circumstances is being remedied by a programme of research and testing in support of design. Ball bearings appear to operate more satisfactorily than needle bearings when run dry. P.T.F.E. impregnated bearings appear to be unaffected by the environment. Their high friction relative to ball bearings makes them of doubtful value in the control mechanisms, except in the hand-wound parts. Wherever possible, provision is made in the design to fit alternative bearings should experience show that it is desirable. Rubbing seals to retain helium have been avoided; so have seals to retain the lubricants because they could be a source of increasing friction and general deterioration.

Reactor Operation

A very simple operating scheme is proposed. Only one motor speed will be used and only one rod at a time will be under the control of the operator. If a fast insertion speed is needed the individual rod will be released to fall free. The reactor core is well able to deal with the shock from such treatment.

One rod will be used for automatic regulation, controlled by a circuit sensitive to gas outlet temperature and, probably, neutron flux changes. Three or four rods will be used as safety rods: they will be controlled from a panel and have circuits separate from the others. These special rods will be chosen by circuit wiring; others may be chosen instead during the life of the reactor, if, for example, fuel burn-up can be evened out in this way.

Of the remaining bank of operating rods the operator will be able to select one and control it by four buttons, raise, lower, release and hold. Normally, movement would continue only while a button is being pressed. Consideration is being given to providing means for the operator, during start-up, to initiate a preset increment of movement which will stop automatically on completion. This could be done with a timer or by counting the pulses to the stepping motor. One emergency button will, of course, release all rods, including safety and automatic rods, simultaneously.

It may be desirable, when more is known about the reactor, to provide more control than is available in the absorber rod system. Provision is made at the bottom of the pressure vessel for mechanisms to be installed, which would operate control elements in the form of graphite moderator rods. These would be lowered out of the core from below to reduce reactivity.

Each of the six moderator rods would form the centre of a block of graphite replacing a fuel element. It would be driven by a rack and pinion, the rack passing down an extension tube in the pressure vessel. The tube would carry the end stops, the bottom one being spring loaded. The pinion could be driven through a gearbox by a stepping motor. A swinging shaft in the gearbox would transmit reaction torque to a spring stop operating a switch.

A permanent-magnet eddy-current brake attached to the motor shaft would control the rate of fall of the element when a free release takes place. The system would not be required to act quickly. Times of about an hour for driving over full stroke, and 30 sec. for subsiding under the control of the brake, have been considered appropriate. When driving with the motor, the brake torque, at the low speed, would be negligible.

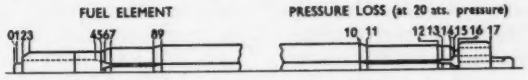

Fig. 1.—Fuel element pressure loss (see Table 1).

(Tuble continued overleaf)

FUEL ELEMENTS: PRESSURE DROP IN COOLANT CHANNEL

Point	Flow area in.²	% void (local)	Perimeter in.	Equiv. Hydrc. diam. in.	Flow area (37 elemnts) cm²	+50cm² at edge = total area
0	18.25	48.2	15.708	4.647 (3.567)	4356	4406
1	11.35	30	18.26	2.486	2709	2759
2	11.35 8.67	30 22.1	18.26 20.68	2.486 1.677	2709 2070	2759 2120
3	8.67	22.1	20.68	1.677 (1.415)	2070	2120
4	6.54	17.3	22.69	1.153	1561	1611
5				(.820)		
6						
7	6.35 7.53	16.8 19.9	52.15 51.68	.4871 .5828	1516 1797	1611 1847
8	7.53	19.9	51.68	.5828 (.4695)	1797	1847
9	4.93	13.0	55.31	.3562	1177	1227
Core Channel	4.93	13.0	55.31	.3562	1177	1227
10	4.93	13.0	55.31	.3562 (.5209)	1177	1227
11	8.68	22.9	50.64	.6856	2072	2122
12	8.68	22.9	50.64	.6856 (1.066)	2072	2122
13	15.90	42.0	43.98	1.446	3795	3845
14	15.90	42.0	43.98	1.446 (2.854)	3795	3845
15	29.30	77.4	27.49	4.263	6994	7044
16	11.00	29	43.98	1	2626	2676
17	11.00	29	43.98	1	2626	2676

(At 20 ats.) Total pressure drop through core = .425 + 2.27 = 2.7 p.s.i.
(At 20 MW output)

Fuel Elements

By ERIC SMITH, B.Sc. (Hons.), A.M.I.Mech.E.
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DRAGON makes wide use of graphite as the most readily available moderating and reflecting material. Graphite, which forms the bulk of the core, also acts as the main structural member of the core, the essential homogeneity of which permits the use of relatively high power densities with practical cooling surface to volume ratios. To meet these requirements a novel form of core construction is proposed in which fuel elements, including fuelled core, moderator and top and bottom reflectors, are restrained in a radial direction by the pressure drop induced in the coolant channels. (Fig 1, Table 1.)

The reflector and fuel elements are mounted on web reinforced bedplates hung from mounting pads on the pressure vessel wall and assembled together by spigoted skirt rings. The skirts allow thermal movements whilst maintaining the concentricity of the assembly. An outer annular bedplate supports the static graphite reflector and the outer ring of pivoted reflector columns whilst an inner circular bedplate supports the fuel elements and the inner ring of pivoted reflector columns. The outer static reflector will be a stacked assembly of bricks made from a high-density graphite and keyed together. The pivoted or "live" reflector columns form two concentric rings surrounding the fuel elements. Each column in these rings is pivoted at its base. The outermost ring of 30 columns has vertical sealing members to minimize inward radial flow of coolant which would otherwise bypass the core zone. The inner ring consists of 30 columns, 24 of which have clearance holes to receive the control (absorber) rods and six provide instrumentation holes. The form of the reflector in this region permits removal by the fuel element handling machine; in this way the graphite most exposed to irradiation damage and other effects can be completely discharged if desired. In addition this facility permits the use of new arrangements of core with changes in outer geometry.

Fig. 1 (p. 303) indicates the distribution of coolant gas flow within the reflector and core, the inlet gases being directed through the reflector to cool the graphite mass and reduce radial heat losses. To prevent complete short circuiting of the coolant gas flow it is necessary to provide a seal between the top of the core and the structure forming the outlet (hot) gas header. It is convenient in this arrangement to make this seal between the outer ring of "live" reflector columns and the annular box-like structure supporting and forming the hot box. The seal must allow free expansion of the core, both radially and vertically, and be absolutely reliable in operation. Associated with the seal there is a core unclamping device to relieve the core of the dead-weight load imposed by the seal and to loosen the assembly of elements constituting the core.

The core zone consists of 37 elements comprising a total

FUEL ELEMENTS: PRESSURE DROP IN COOLANT CHANNEL. TABLE 1.

Average He. temp °C	He. flow cc/sec cm^3	Velocity v cm/sec	Density δ at 20 Ats.	Viscosity μ poises	Reynolds No. Re	L in.	$\frac{L}{D}$	Velocity head equivalent p.s.i.	Friction factor $4f$	Friction loss p.s.i. $\times 10^4$	Velocity heads lost at section changes	Section change pressure loss p.s.i. $\times 10^5$
350	6.15×10^6	1396	15.64×10^4	3.22×10^4	80,000			.0221			.5	110.5
						.625	.1752	(.0392)	.0192	1.3		
350	6.15×10^6	2229	15.64×10^4	3.22×10^4	68,360			.0564			.05	28.2
						1.22	.4907		.0200	5.5		
350	6.15×10^6	2229	15.64×10^4	3.22×10^4	68,360			.0564				
350	6.15×10^6	2901	15.64×10^4	3.22×10^4	60,020			.0955			.1	95.5
						1.063	.6338		.0204	12.9		
350	6.15×10^6	2901	15.64×10^4	3.22×10^4	60,020			.0955				
						.375	.2650	(.1304)	.0208	7.2		
350	6.15×10^6	3818	15.64×10^4	3.22×10^4	54,300			.1654			.05	82.7
						8.4375	10.290	(.1760)	.0228	412.9		
350	6.15×10^6	4057	15.64×10^4	3.22×10^4	24,370			.1867			.05	93.3
350	6.15×10^6	3330	15.64×10^4	3.22×10^4	23,930			.1258			.02	25.2
						2.75	4.719		.0244	144.8		
350	6.15×10^6	3330	15.64×10^4	3.22×10^4	23,930			.1258				
						.80	1.704	(.2053)	.0248	86.8		
350	6.15×10^6	5012	15.64×10^4	3.22×10^4	22,020			.2849			.05	142.5
—	—	—	—	—	—	63	176.9	—	—	22,700	—	—
770	10.3×10^6	8394	9.32	4.58×10^{-4}	15,450			.4763			.18	857.3
						.800	1.536	(.3178)	.0270	132.8		
770	10.3×10^6	4854	9.32	4.58×10^{-4}	17,190			.1592				
						4.25	6.200	(.1578)	.0268	262.2		
750	10.1×10^6	4760	9.52×10^{-4}	4.53×10^{-4}	17,410			.1564			.16	250.2
						.5	.469	(.1020)	.0264	12.6		
750	10.1×10^6	2627	9.52×10^{-4}	4.53×10^{-4}	20,280			.0477				
						1.25	.865		.0260	10.7		
750	10.1×10^6	2627	9.52×10^{-4}	4.53×10^{-4}	20,280			.0477			.21	100.2
						.308	.108	(.0309)	.0244	.8		
750	10.1×10^6	1434	9.52×10^{-4}	4.53×10^{-4}	32,640			.0142				
						.442	.104		.0236	.3		
750	10.1×10^6	3774	9.52×10^{-4}	4.53×10^{-4}	20,150			.0983			.3	294.9
						5	5		.0260	127.8		
750	10.1×10^6	3774	9.52×10^{-4}	4.53×10^{-4}	20,150			.0983			1	983

Totals (without core friction) 1218.6 3033.5

Total end losses (at 20MW) = .122 + .303 = .425 p.s.i.

of 259 fuel rods, which together make up the active core, and the top and bottom reflectors. Every element is pivoted near its base; a cone-shape seating in the fuel element sitting onto the spherical end of a spike through which the fission product purge flow is exhausted into the fission product clean-up circuit. The detail design of the proposed fuel element for the first charge in this experiment is described in the succeeding paragraphs. A plan view of the core region is shown in Fig. 2.

The core design must be such as to produce an effectively homogeneous mixture of fuel (uranium^{235}), breeder (thorium^{232}) and moderator (graphite). A mixed outlet gas temperature of 750°C is required with a core thermal output of 20 MW. Helium at 20 atmospheres pressure has been chosen as the working fluid and an inlet temperature of 350°C is required. The element must provide adequate means for fission product control, be suitable for use with either fission product retaining or emitting inserts and designed so that the activity in the primary circuit is kept to an acceptably low limit. An active loading of about 20 kg of uranium^{235} and 135 kg of thorium^{232} is envisaged.

A general arrangement of the fuel element designed to fulfil the requirements already outlined is shown in Fig. 3. The element consists of seven fuel-rod assemblies each of which incorporates: at the top end (i) Orientation dowels (ii) Scavenge gas inlets (iii) Porous plug (iv) Growth safety washers (v) Top filler piece; in the centre (i) Fuel rod tube (ii) Fuel boxes (10) (iii) Fuel inserts (six per box) (iv) Graphite centre pieces (one per box) and at the bottom end (i) Low expansion alloy cap nut with compensating bellows (ii) Scavenge gas exit.

The upper end of each rod is connected to a top-block of graphite (Fig. 4) by chrome-steel cap bolts suitable for operation in the hot outlet gas. The bolt portion of these caps is a free slide fit in positioning holes in the top-block and the spacing of the holes defines the rod pitch. While the pitch is thus rigidly defined each rod is mounted to the block with an endwise flexibility using diaphragm type washers. This flexible form of mounting will accommodate initial irregularities or subsequent non-uniform behaviour of the seven rods forming a single element and assists load sharing during handling. During operation in the core gross changes in any of the rods forming a bundle will cause these washers to yield and thus avoid undue stresses in the material of the fuel tube. Dowels in the top-block assembly ensure correct orientation of the fuel rod faces and serve to prevent loosening of the top caps. The top-block is reinforced for handling purposes by a metal cylinder with direct metal coupling to the through bolts.

To keep activity in the main circuit to acceptably low limits fission product control is provided within each fuel element assembly as follows. First, the fuel bearing insert is enclosed in a fuel box made from graphite impregnated to reduce its permeability to such a level as to delay the diffusion of volatile fission products through its wall for at least one hour (Fig. 5). A gap between the fuel box and the fuel tube wall is scavenged by a purge flow of helium admitted from the main coolant stream through a porous plug at the head of each rod. This purge flow dilutes the fission products in the interspace between box and tube and so reduces the activity passing out through the walls of the fuel tube. The fuel tube is also made from graphite treated to give a low permeability so that (i) inward flow of coolant is reduced to negligible quantities, and (ii) outward diffusion of volatile fission products is reduced to low limits.

For assembly purposes, the porous plug is retained by a graphite screw. A small central hole passes the scavenge flow through at a suitable velocity. Loosening or even breakage of the screw does not invalidate the principle of this design. The fuel box is also of some value in limiting fission product damage to the main structural item of the fuel rod assembly and gives reasonable permanence to the small purge flow gap.

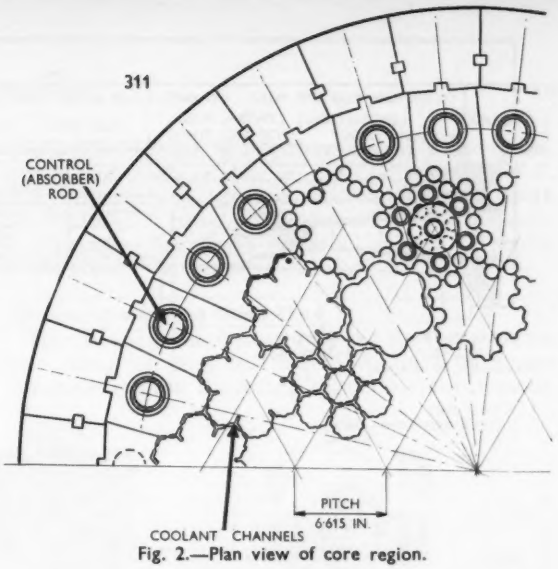


Fig. 2.—Plan view of core region.

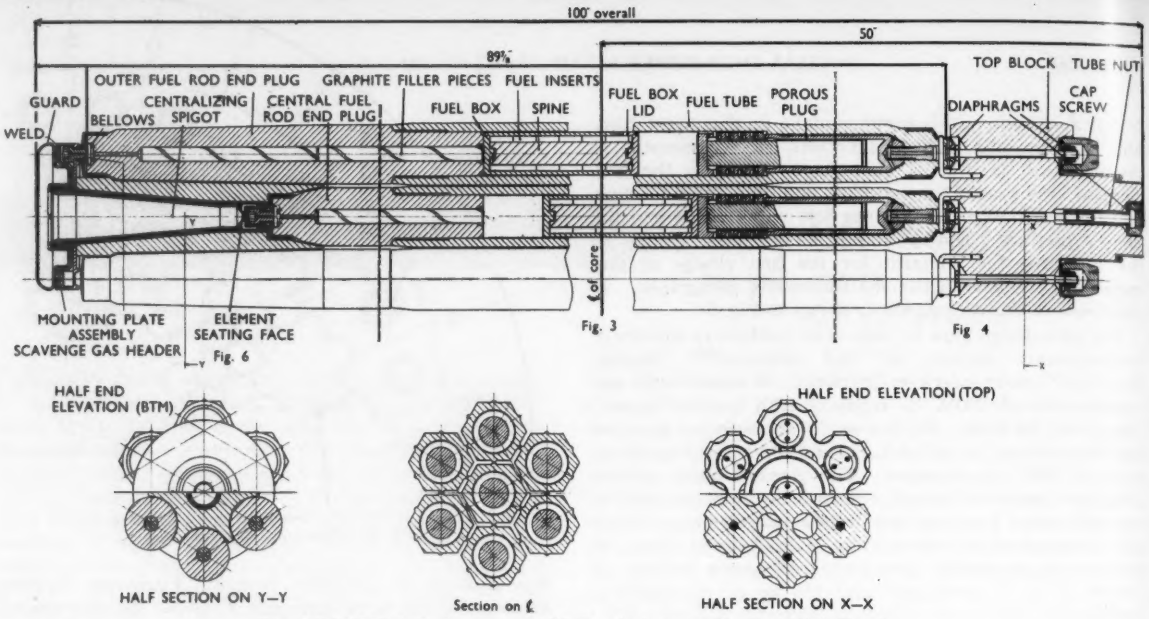
An all-steel header plate forms a mounting to which all seven rods are attached at the bottom end of the assembly by means of low-expansion nickel alloy cap nuts with integral single convolute bellows (Fig. 6). The bellows minimizes stresses induced during the brazing of the cap nut to the graphite fuel tube plug and during operation at temperature. The welded mounting assembly acts as a gas-tight header for the purge flows down each rod and leads the purge from all rods to a common exit at the mounting spike seat.

Within each fuel box an end clearance allows for the growth of the inserts and/or shrinkage of the graphite box. In the fuel tube a group of safety washers at the top of each set of 10 boxes acts as a spacer which will fracture progressively before undue stresses can be imposed on the tube. Each fuel box contains six fuel inserts of annular form threaded onto a central graphite filler rod. At the point between the fuel tube and its end plug one face is provided with serrations. By crushing under small loads these serrations prevent overloading of the threads due to eccentricity, the inclusion of foreign bodies in the joint, etc., and they also improve leak tightness. A supplementary braze may be made at this point.

The choice of fuel rod pitch is somewhat arbitrary within the broad limitations imposed by permissible thermal stresses and reliable heat-transfer performance at full and part load. The aim has been to make each rod sufficiently robust and to choose a suitable geometrical arrangement for the core. A triangular pitch of 2½ in. with 259 fuel rods has been found suitable for these requirements.

Choice of the coolant channel shape has been based on the following considerations: (i) Some form of restraint is necessary to prevent closure beyond a satisfactory minimum; (ii) local heat transfer coefficients should be as uniform as possible within the channel; and (iii) changes in core dimensions with temperature and other effects must not modify the heat transfer performance unduly.

A smooth channel rather than extended surfaces has been preferred in this experiment because there is no serious limitation imposed by the centre fuel rod temperatures and it is desirable to keep the pressure drop to reasonably low values. It was also felt that the notch effect of extended surfaces cut into the graphite might impair the mechanical behaviour of the rods.



The DRAGON fuel element. (Left) Fig. 6, (centre) Fig. 3, (right) Fig. 4.

The decision to construct a single element using seven fuel rods was based on several considerations. For example, (i) it reduces the total number of elements to be handled to a conveniently low figure and saves time at unloading and loading; (ii) the fission product scavenge system is simplified by a reduction in the number of outlet connections required; (iii) the effective load of the element on its seating is sufficient to give satisfactory sealing (about 120 lb in this design). The effective load is the weight minus the resultant pressure force on the element due to coolant flow; (iv) operation of the loading machine is simplified by a large pitch.

To achieve an effectively homogeneous core it is not necessary to disperse the fuel uniformly throughout all the moderator; the design proposed is sufficiently homogeneous and has the advantage that the fissile assemblies (fuel boxes) are sufficiently small for convenience in handling and assembly. The vertical rod form of the construction simplifies the fission product control problem.

Heat Transfer

The heat transfer performance of the smooth trefoil shaped channels has been based on correlation data from tests by Humble, Lowdermilk and Desnion in the U.S.A. in which high bulk temperatures and high thermal fluxes were used. The equation can be presented in the form

$$\left[\frac{hD}{k_f}\right] = 0.034\left[\frac{L}{D}\right]^{-0.1}\left[\frac{GD}{\mu_f}\right]^{0.8}\left[\frac{T_b}{T_f}\right]^{0.8}\left[\frac{C_{pf}\mu_f}{k_f}\right]^{0.4}$$

where h = heat transfer coefficient
D = effective channel diameter
k_f = thermal conductivity evaluated at film temperature
L = channel length
G = mass flow per unit area
μ_f = viscosity evaluated at film temperatures
T_b = mean bulk coolant temperature
T_f = film temperature—defined as $\frac{T_b+T_s}{2}$ where
T_s = heat transfer surface temperature
C_{pf} = specific heat at constant pressure evaluated at film temperature

The temperatures predicted in this design of fuel element using the above correlation are given in Table 2 for a mean channel. In arriving at these values is has been assumed that:–(i) The thermal conductivity of the graphite may be reduced by a factor of two during the lifetime of the element in the reactor (a value of 0.03 cal cm^{-1} sec^{-1} $°C^{-1}$ at 700°C has been used).

(ii) Heat transfer through the fission product scavenge gap is by conduction and radiation only (an emissivity coefficient of 0.75 has been used).

(iii) There is no gap between the fuel insert and the fuel box wall.

A full analysis to predict the temperatures in the hottest operating channel has not yet been possible; it is, however, expected that the values generally will be increased by about 150°C at the heat transfer surface and 250°C in the centre of the assembly of a rod. This means that the maximum temperatures which may be expected inside a fuel box assembly will be of the order of 1,700°C. Many factors affect and modify these peak temperatures: (i) The neutron flux distribution, (ii) radiation of heat into the reflector, (iii) conduction and convection of heat into the reflector, (iv) cross-flow mixing between channels, (v) variations in size of channels, (vi) gap variations between rod and box, (vii) variations at the fuel insert box boundary, and (viii) thermal flow disturbances in the channels.

TABLE 2

Core with 37 Fuel Elements operating at 20MW(T) Output

Coolant Helium at 20 Ats. absolute:	
Coolant flow (Total)	9618 gm/sec
Area of one coolant channel	2.27 cm^2
Mean hydraulic diameter	0.905 cm
Heat rating of rod	482.6 W/cm
Heat flux at cooled surface	24.0 W/cm^2
Mean coolant voidage in core	13.1%
Total core voidage	15.5 to 16%

	Mean Bulk Coolant Temperatures			Units
	350	550	750	C°
Density (ρ_b)	1.57	1.19	0.95	$gm/cm^3 \times 10^2$
Velocity (v_b)	4.83	6.39	7.94	$cm/sec \times 10^{-3}$
Viscosity (μ_b)	3.27	3.94	4.57	$poises \times 10^{-4}$
Reynolds Number (bulk) (Re_b)	2.10	1.74	1.50	$\times 10^{-4}$
Reynolds Number (Mod) (Re_{med})	1.62	1.43	1.29	$\times 10^{-4}$
Heat transfer coeff. (h)	0.12	0.12	0.13	
Heat transfer temp. drop	208	202	192	°C
Surface temp. of fuel rod	558	752	942	°C
Temp. drop through fuel rod wall	188	188	188	°C
Wall temp. in fuel rod bore	746	940	1130	°C
Temp. drop in gap (0.0127 cm)	134	120	110	°C
Wall temp. of fuel box	880	1060	1240	°C
Temp. drop through fuel box wall	110	110	110	°C
Fuel surface temp.	990	1170	1350	°C
Temp. drop through fuel	108	108	108	°C
Inner fuel and spline temp.	1098	1278	1458	°C

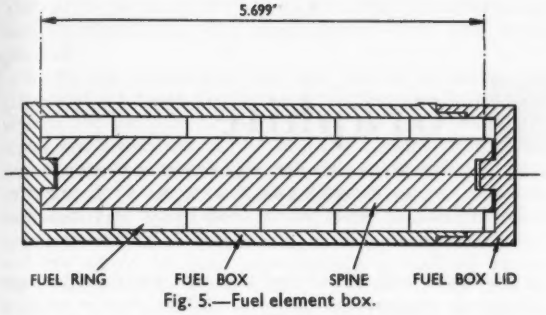


Fig. 5.—Fuel element box.

For a large number of performance calculations where a comparison of effects produced by design changes is required, it was found convenient to rewrite the correlation equation quoted earlier in the form:

$$\frac{\phi D^{0.2}}{G^{0.8}}\left[\frac{L}{D}\right]^{0.1} = 0.068\,\frac{k_f^{0.6}\,C_{pf}^{0.4}}{\mu_f^{0.4}}\left[T_f - T_b\right]\left[\frac{T_b}{T_f}\right]^{0.8}$$

where ϕ=Thermal flux at the transfer surface.

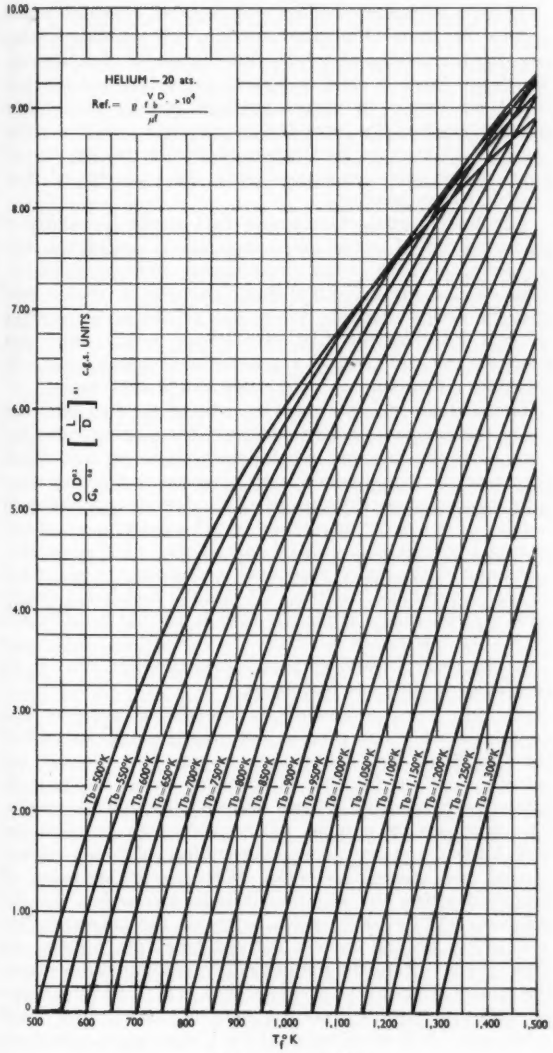


Fig. 7.—Values of T.

The right-hand side of this expression can be plotted for a given coolant as a function of T_f for various values of T_b (Fig. 7) while the left-hand side includes the design parameters and can be quickly evaluated for a particular arrangement. The curves can then be used to predict T_f and hence T at any value of T_b.

Thermal Stresses and Other Data

Thermal stresses in the fuel tube and the fuel box have been calculated using the formula for stress in a long cylindrical member conducting heat in a radial direction, viz.:

Radial Stress

$$\sigma_r = \frac{E\alpha T}{2(1-\mu)} - \left[\frac{1}{b^2-a^2}\left[\frac{a^2b^2}{r^2} - a^2\right] - \frac{\ln b/r}{\ln b/a}\right]$$

Circumferential Stress

$$\sigma_\theta = \frac{E\alpha T}{2(1-\mu)}\left[\frac{1-\ln b/r}{\ln b/a} - \frac{1}{b^2-a^2}\left[a^2+\frac{a^2b^2}{r^2}\right]\right]$$

Axial Stress

$$\sigma_z = \frac{E\alpha T}{(1-\mu)}\left[\frac{1-\ln b/r}{2\ln b/a} - \frac{a^2}{b^2-a^2}\right] \quad \text{(no axial constraint)}$$

No attempt has been made to refine these calculations at this stage to take account of the known anisotropy of the materials in question as the physical properties to be used are by no means certain. Evaluation of the appropriate properties is the subject of a current programme of study. In the calculations that have been made the following values have therefore been used:—

Young's modulus $E=2.8\times10^6$ p.s.i.
Poisson's ratio $\mu=0.25$
Coefficient of linear expansion from:—
Thermal strain (from 100°C)
$\epsilon T = 1.0\times10^{-6}(T_1-T_0)+1.75\times10^{-9}(T_1-T_0)^2$
where $T_0=100$°C
and T_1=operating temperature
e.g. α mean (600 to 800°C)=

$$\frac{C\ 800 - C\ 600}{200}$$

In addition to the thermal stresses set up by temperature gradients the fuel box may be subjected, under certain conditions, to considerable pressure differences. Such situations may arise principally on starting up and closing down the reactor or during a fault condition in which the coolant pressure falls quickly. The greatest stress induced in the fuel box wall under such conditions is due to the discontinuity introduced by the end cap and lid.

The preceding paragraphs have described the form of fuel element and the core arrangement proposed at this date for the DRAGON Reactor Experiment. The design study of the proposals continues and some changes may be expected though the underlying and basic form is not likely to change for the first charge. Much has yet to be learned from high-temperature irradiation studies and the DRAGON materials group is constantly striving to produce better inserts and tube materials.

Graphite

By R. A. U. HUDDLE (*Head of Materials Branch*), P. A. P. ARRAGON and M. S. T. PRICE (*Graphite Section, Materials Branch*), *OEEC High Temperature Reactor Project, AEE, Winfrith*

THE basic philosophy of the DRAGON system involves the use of a core and reflector constructed almost entirely from graphite. In all other graphite moderated systems to date, graphite is merely the moderator and is quite separate from the fuel element and fission products: in the HTGCR system it is not, and this has a marked influence on the design philosophy of the system as a whole.

The sole use of graphite within the core as the structural material for canning and as the fuel dispersion medium has many advantages over the conventional system employing metal-clad fuel elements, but at the same time it brings with it a number of problems involving the development of new graphites having properties specific for each particular component. Because the properties required for the various components differ markedly, as many as five different types of new graphites are required in quantity for the DRAGON programme.

The special graphites that are now in the course of development are rather like the alloys of a parent metal: their properties are often quite different from the elementary material—as is their price. Whereas in the core of existing gas-cooled power reactors approximately 2.5 tons of graphite are required per MW(t), in the HTGCR system the power densities in the core are greater and only about 0.1 ton of graphite is needed per MW(t).

The engineering design of the Reactor Experiment has been based on the properties of a commercially available fine-grain graphite, Morgan Crucible's EY9—and its special derivatives. With the exception of permeability (and, possibly, purity) no major design problems have arisen. However, the basic requirements of purity, high density and controlled permeability—or more strictly controlled diffusion characteristics—in addition to the behaviour under irradiation, necessitate further research.

In a small reactor, such as an HTGCR, purity is not so important as in a Magnox reactor. Moreover, the possibility of employing a burnable poison, such as boron, within the core—to facilitate control so as to increase the life of a charge—must not be overlooked. The presence of boron is, therefore, not necessarily deleterious provided it is consistent from batch to batch and homogeneous within each batch.

The requirement for a high-density graphite arises primarily from nuclear physics considerations which, in turn, determine the economics of the system. In order to obtain high power densities with good neutron economy it is essential to employ high-density graphite, and it is hoped that materials of the order of 2.0 ± 0.05 g/cm^3 will be developed.

The problem of permeability is far more complex, for there are two diametrically opposed basic requirements for the fuel elements: one in which all fission products are returned, the other in which all are emitted.

Present proposals for the Reactor Experiment involve the use of a fuel box (approximately 6 in. long by 1¼ in. dia.), 10 of which fit inside each fuel rod can. Although the primary objective of the fuel box is to facilitate fission product control, it also prevents fission fragment damage to the inside wall of the fuel rod can, which is the main structural component of the core. Whilst there is no proof that fission fragment damage would be serious, there are theoretical grounds for expecting the damage to be orders of magnitude worse than damage by neutrons, etc. Furthermore, the fuel box is a very convenient unit from the fabrication and assembly point of view as it provides flexibility within the fuel element—so essential in a reactivity experiment. Furthermore, the design of the DRAGON Reactor enables both fission product retaining and fission product emitting fuel elements to be studied as special experimental elements.

The use of fission product emitting fuel elements would reduce or even eliminate problems of poisoning, thus opening the way to very high fuel burn-ups. Fuel inserts, which are made by cold compacting uranium and thorium metal powders with excess graphite powder and subsequently reacting to form the appropriate carbide, either during fuel element fabrication or in the reactor, should emit, under operational conditions, the majority of their volatile fission products.

For fission product retaining fuel elements (which, if perfected would avoid the complications associated with an active primary circuit) two approaches are available. One, to coat the individual fissile particles in such a way that the fission products do not escape, the other to make a truly impermeable fuel box which would carry out precisely the same task as a conventional metallic can. In this case a combination of the two seems appropriate.

In the Reactor Experiment the rôle of the fuel box is to delay the escape of fission products, for a minimum fixed time, from the fuel box into the flushing gas stream, which then entrains the gaseous fission products and carries them into the fission product traps. Calculations are based on a delay of one hour: this should be achieved with a fuel box having a permeability of 10^{-6} cm^2/sec and a leak-tight seal.

As one of the major objectives is to study the behaviour of fission products it is essential that the fuel boxes should have a permeability within fixed limits, so that the diffusion of the various fission products (including their precursors and daughters) should have approximately the same behaviour in different fuel boxes.

At this point it seems appropriate to consider the complexity of fission product diffusion through the wall of the fuel box. This takes place by gas flow through the pores by surface diffusion of adsorbed atoms on the walls of the pores and by volume diffusion through the grains. The problems of gaseous diffusion through graphite are well known and have been the subject of much experimental and theoretical work. With surface diffusion of adsorbed atoms the situation is indeed complex, for the diffusion will be taking place partly on the graphite grain and partly on the carbon derived from the binder and impregnant. Regarding volume diffusion within the grains, the crystal structure of graphite gives rise to an anisotropy of diffusion possibly not exceeded in any other solid substance. It is therefore doubtful if theoretical considerations are of much value in such a complex system—

whether or not the results can be predicted by mathematical analysis must await the experimental work now being planned.

Whilst the function of the fuel box is to reduce the activity of the fission products escaping into the flushing gas stream, the purpose of the fuel rod can is to reduce the direct contamination of the primary coolant circuit. As with the fuel box (a truly impermeable fuel box would have to be used in conjunction with fission product retaining fuel inserts to avoid pressure build-up of volatile fission products leading to burst cans), a truly impermeable fuel rod can would be ideal; alternatively, a material having 100% viscous flow would suffice. Initially it was thought that this latter principle would be satisfactory, but experiments with EY9 showed that a significant fraction of the flow was molecular, and thus ineffective for preventing back diffusion of fission product gases. It was therefore necessary to abandon the principle of flushing through the can wall and to restrict diffusion by impregnation. This necessitated the development of a material having a permeability of 10^{-5}—10^{-6} cm²/sec. Should it be possible to produce graphites of permeability of 10^{-2}—10^{-3} cm²/sec having 100% viscous flow, then this material would be satisfactory for the fuel rod cans.

It is important to appreciate the different requirements of the fuel box and the fuel rod can. The fuel box must be leak-tight or, more strictly, it must have a permeability that will provide a transit time through any leak path of at least one hour. On the other hand, the fuel rod can and other components of the fuel element have only to prevent back diffusion of fission products into the primary circuit: cracks, pinholes, etc., in components and joints that have a negligible molecular flow component are unimportant.

The success of any new reactor is ultimately determined by its behaviour in service. For the graphite, this means its behaviour in the presence of radiation and fission products at high temperatures; in the Reactor Experiment the centre graphite temperature will be 1,700°C with the fuel boxes at 1,500°C. The essential characteristics, i.e. permeability and diffusion thermal conductivity, mechanical properties and dimensions, must not change significantly. Whilst some of this information can be obtained from capsule and loop experiments in research reactors, certain important phenomena, such as the bowing due to thermal and irradiation flux gradients of fuel tubes and the inner reflector graphite, can only be assessed satisfactorily under service conditions.

The use of helium as coolant avoids any inherent corrosion and mass transfer phenomena. However, problems due to impurities arise, and as the adsorbed gases on graphite constitute the major source of contamination it is essential that the fuel elements should be completely degassed on loading into the reactor. Although our knowledge of the degassing and regassing characteristics of the special graphite employed is as yet limited, it is known that the principal gas adsorbed is water, and that temperatures of the order of 2,000°C, in vacuum, are required for degassing. In the degassed state graphite is as good as, if not a better desiccant than, phosphorous pentoxide. This necessitates the use of dry box conditions during assembly of the fuel elements and during loading into the reactor.

The graphite requirements for the Reactor Experiment can be divided into three main groups: the outer reflector, the inner removable reflector and the fuel elements. These requirements have been integrated into the general development programme, which includes supply of material for the out of pile seven element test rig, for a dummy charge for commissioning the Reactor Experiment, and for the first charge itself.

The prime need for the reflector is that it should be of high purity, high density and should be dimensionally stable under irradiation at about 350°C. These requirements suggest the use of a fine-grain material and development work is now in progress with Société Pechiney at Chedde (Haute Savoie, France) to develop such a material having a density of at least 1.9 g/cm³.

For the inner reflector, which is removable, any good quality nuclear graphite of the required dimensions can be used initially. Subsequently, high-density material will be developed.

For the fuel element, the major graphite components of the present design are: (1) the top block; (2) the fuel rod can and fuel rod end; and (3) the fuel box, fuel inserts and centre graphite.

The fuel rod cans have been the subject of a major research and development programme. The initial requirement was for a rod just under 6 ft long with a dia. of 2¼ in. having a permeability of about 10^{-2} cm²/sec. This led to the choice of Morgan Crucible's EY9. Subsequent work showed the necessity for impregnation and a satisfactory process has been developed at the Royal Aircraft Establishment, Farnborough, and at Hawker Siddeley Nuclear Power at Langley. This work was described in papers presented at the DRAGON Graphite Symposium held in Bournemouth in November, 1959. It is intended to publish the proceedings of this Symposium shortly. The change of core dimensions at the end of 1959 resulted in a requirement for stock materials for fuel rods, 6 ft 6 in. in length and about 3¼ in. in diameter. The manufacture of material of these dimensions in the quality required for impregnation has proved most difficult and great credit is due to the technical staff of the Morgan Crucible Co. for their success in this field. The stock material for the reactor now designated CY119 has been ordered and deliveries have commenced. After heat treatment in the temperature range 2,500°-3,000°C—with or without purification—the fuel rods are machined; initial requirements for the seven element test rig are being machined at the U.K. AEA graphite machine shop at Bracknell. After machining impregnation will be carried out using the R.A.E. furfuryl alcohol impregnation process as developed by the Hawker Siddeley Nuclear Power Co.

As with the fuel rod cans, fuel boxes for the first charge will be made from CY119 impregnated by the furfuryl alcohol process. Sealing will be carried out in the fuel element assembly line at Winfrith using a zirconium braze. This will probably be carried out in conjunction with the final degassing operation.

The present specification for fuel inserts involves cold compacting the uranium, thorium and graphite powders and assembling them in the green condition, with the centre graphite, into the fuel box. If a burnable poison is employed the boron will be incorporated either in the fuel insert or in the centre graphite, which would in any case be made from a dimensionally stable high-density material.

Although the primary objective of the graphite work has so far been concentrated on ensuring the supply of a suitable core and reflector for the first charge within the time scale dictated by the overall reactor programme, future requirements have not been neglected. It is hoped that during the next few years the major objectives will have been reached and that specifications for graphites for all major requirements of the Project will be available. To this end development programmes have been discussed with the major graphite suppliers in Europe and contracts for research and development are being negotiated with Société Pechiney (Paris and Chedde) and with Ringsdorff-werke (Bad Godesberg, West Germany). Their programmes will be supported by work in the Experimental Graphite Plant at Harwell.

The Nuclear Power Programme

U.K. Government Issues New White Paper on June 20*

THE latest White Paper on the U.K. Nuclear Power Programme indicates a further slowing down of the bold, ambitious scheme to provide 5,000 to 6,000 MW by 1966. The date for completion of the programme is now 1968. Orders for nuclear stations will continue to be placed at the rate of one per year. The full text of the White Paper is as follows:

Introduction.

In 1955 "A Programme of Nuclear Power" (Cmd. 9589) was presented to Parliament outlining provisional proposals for the building of nuclear power stations to give a capacity of 1,500-2,000 MW by 1965. Because of the fuel situation and the further technical progress that had been made, the Government announced in March, 1957, its intention to accelerate this programme and adopt it as the basis for planning a range of 5,000-6,000 MW of nuclear capacity by the end of 1965. Due to restrictions on capital expenditure it was announced in October, 1957, that this state would be extended to the end of 1966. Details of this expansion were given in the Appendix to the White Paper on "Capital Investment in the Coal, Gas and Electricity Industries" (Cmd. 132) presented to Parliament in April, 1957. Five nuclear power stations are being built and two more have been approved; the earlier stations will come into operation in 1961 and all seven should be in operation by 1966. These seven stations will have a total output capacity of approximately 3,000 MW. To reach a total capacity of 5,000 to 6,000 MW by the end of 1966 it would be necessary for the Electricity Authorities to place exceptionally large orders for nuclear capacity during the next two years for commissioning in 1965 and 1966.

2. Since 1957 coal has become plentiful and oil supply prospects have also improved. The need on fuel supply grounds for an immediate and sharp acceleration in the rate of ordering nuclear capacity has therefore passed.

3. The English and Scottish Electricity Authorities in consultation with the Atomic Energy Authority have therefore re-examined the programme with the Government in the light of these changes and of the latest estimate of nuclear and conventional costs and the future availability of primary fuels to meet our growing energy needs.

Comparative Costs of Nuclear and Conventional Power.

4. Although the cost of electricity from the first nuclear stations to be commissioned next year will be rather higher than earlier estimates, the costs of later stations are following closely the downward trend foreseen in 1957. What was not then foreseen was the extent of the fall which has also taken place in the costs of conventional power from new stations. The development of large generating sets has reduced the capital cost of these new stations, the use of higher steam temperatures and pressures has increased their efficiency, and careful siting near to low-priced coal sources has reduced the delivered cost of coal to them. But, nuclear costs in which capital charges are the major element, are falling even faster. For stations designed today, conventional power costs are about 25 per cent. less than nuclear costs in the United Kingdom but the Government is advised that nuclear generation for base load purposes is likely to become cheaper than conventional generation by about 1970.

Primary Fuel Supplies.

5. Despite the present world surplus of coal and oil, we still face the eventual prospect that our growing energy demands will call for more and more supplies of nuclear power. By 1975 power stations will be consuming the equivalent of some 125 million tons of coal a year—well over double the present rate—and by 1980 their annual requirements could well reach the equivalent of 200 million tons of coal. Although oil seems likely to remain plentiful for many years it would not be prudent to rely only upon imported oil to supplement coal to the extent implied by these estimates.

6. In the long run we shall therefore need increasing supplies of nuclear power. In about 10 years' time it should be cheaper to generate base load in nuclear stations than in conventional stations provided that we achieve the technological progress that is expected. To ensure this we must continue to build nuclear stations on an adequate scale.

The Immediate Future.

7. In these circumstances the Government has decided, in agreement with the Authorities concerned, that the national interest will best be served by continuing, for the time being, to place orders for nuclear stations at the rate of roughly one every year. The capacity of individual stations is likely to increase, so that the effect of this decision should be a steadily rising rate of nuclear commissioning which should give the country about 5,000 MW of capacity in 1968.

Capital Cost.

8. Compared with the 1957 programme and after allowing for more conventional stations, it is estimated that this rate of ordering will reduce by some £90 million the cost of power stations to be commissioned during the next seven years. There will, however, be some loss to the Atomic Energy Authority.

The Nuclear Plant Industry.

9. The proposed rate of ordering means that at any time there should be five or six stations in various stages of development from design to commissioning. This should fully maintain the rate of development of our nuclear technology and should also sustain a nuclear plant industry capable of competing for overseas business and of expanding to meet the higher level of our future needs. The Atomic Energy Authority's prototype of the Advanced Gas Cooled Reactor at Windscale is now nearing completion and the placing of an order for a commercial scale station of this design will be considered when sufficient information is available.

Press Conference

At a Press Conference following publication of the White Paper, the Minister of Power, the Rt. Hon. Richard Wood, M.P., Sir Christopher Hinton, Chairman, CEGB, and Sir Roger Makins, Chairman, AEA, answered questions. It was made quite clear that the slowing of the nuclear programme is essentially due to the lowering of costs of conventional fuels.

Sir Roger said the main effect on the AEA's costs would be an increase in the interest charges on the uranium stock-piled as a result of the cut. Sir Christopher said that so far as the CEGB was concerned the amount of nuclear capacity at the end of 1966 under the new programme would be 3,175 MW (at a cost of £410 million) compared to an estimated 4,475 MW (at a cost of £530 million) under the old programme. The order for Dungeness will be placed in a few weeks; the order for Sizewell will be towards the end of 1960. After that nuclear stations will be ordered at the rate of one a year. An order for an AGR station will probably be additional to this figure. The CEGB expects the base load in 1970 to be in the region of 6,000 MW. The current estimate for future demands of electricity is at the rate of 6.9% compound per year although there may be some slight falling off.

* The Nuclear Power Programme, June, 1960. (Cmd. 1083) H.M.S.O. Price 4d. net.

World Power Conference

Our own correspondent reports this year's Sectional Meeting in Madrid

AGAINST the background of a surplus in coal supplies and the exploitation of such energy reserves as the Lacq gas and the Sahara oil fields the contributions to the Conference regarding nuclear energy were more restrained and more firmly based than has been apparent in many such meetings held over the past five years. The influence of real construction and operating experience is being felt and even those papers concerned mainly with forecasts exhibited an analytical, down-to-earth approach devoid of either undue pessimism or optimism.

The subject of practical load factors dominated the discussion in the opening session which was concerned with the establishment of nuclear reactors on an industrial scale. This was introduced by the suggestion that in economic calculations a figure of 75% was too high and could be more realistically replaced by one of 65%. Against this opinion, the record of those reactors at Calder Hall and Chapelcross which had been operating for a sufficient time for statistical information to be valid was quoted. It was emphasized that it was necessary to distinguish between the system demand load factor, a function of the system size and method of operation and the plant availability. The overall availability from the AEA's Magnox reactors was greater than 80% and if one subtracted the time taken for off-load charge/discharge it was greater than 95%. Of the remainder one third could be attributed to planned experimental work. The civil stations would contain on-load fuel changing equipment but would be running the elements to nearer their ultimate life. An availability factor of greater than 80% should be quite practical however, particularly as an analysis of a representative sample of 1,500 fuel elements irradiated to over 1,300 MWd/t had shown that only one fuel element failure need have led to shut-down.

TABLE I

	EDF 1	EDF 2	EDF 3	
			A	B
Fuel	Natural uranium magnesium clad			
Diameter of uranium (cm)	1.4–3.5	1.8–4	2–4	2–4
No. of elements per channel	15	12	15	12
Length (cm)	60	60	60	60
Diameter over fin supports (cm)	8.1	10.3	—	—
Total uranium (tonnes)	142	237	440	330
Moderator	Graphite			
Lattice (cm)	Sq. lattice at 19.6 (256 channels) and 22.4 pitch (892 channels)	Hexagonal lattice 13.0 pitch	Hexagonal 13.9 pitch	Hexagonal 13.8 pitch
Diameter (m)	9.5	14.2	17.8	17.5
Height (m)	10.02	8.4	10.2	8.4
Diameter of the active part (cm)	8.3	12.2	15.8	15.5
Height of the active part (m)	9	7.2	9	7.2
No. of fuel channels	1,148	1,977	3,160	3,080
Diameter of fuel channels (cm)	8.4	10.3	11.9	11.1
Vessel	Cylindrical	Spherical	Spherical	Spherical
Diameter (m)	10	18.3	22.5	21
Height (m)	23	—	—	—
Thickness (cm)	10.8	8	9.7	9.1
Pressure (hpa)	25	25	25	25
Capacity				
Thermal power (MW)	294	791	1,570	1,175
Turbine power (MW)	6	22	48	36
Maximum electrical output (MW)	80	232	500	375
Net electrical power (MW)	70	198.5	427	320
Net output	0.238	0.251	0.272	0.272
Reactor				
Average specific power (MW/t)	2.07	3.33	3.62	3.5
Maximum specific power (MW/t)	4.8	5.8	6.2	6.4
Maximum heat rating of elements W/cm³	67	82	87	89
Power output of hottest element (kW)	375	496	615	509
Max. uranium temp. (°C)	550	585	590	590
Max. cladding temp. (°C)	400	424	435	435
CO_2				
Delivery (kg/s)	1.360	4.420	8.600	6.450
Reactor entrance temp. (°C)	142.5	198	200	200
Reactor exit temp. (°C)	345	265	370	370
Exchanger entry temp. (°C)	345	365	370	370
Exchanger exit temp. (°C)	139	194	195	195
Loss in the reactor (pièzes)	84	65	—	—
Overall loss (pièzes)	116	110	—	—

The same view was not shared by all speakers—some of whom were clearly influenced by their own personal experience (or lack of experience). Understandably the U.K. representatives were able to express greater confidence in the maintenance of a high load factor (with suitable cautionary provisos) because of the AEA's record, the current tradition of designing conventional plant with significant reserve in hand and the large base load capacity distributed through the national grid.

Progress of the French atomic energy programme was reviewed[2, 3] as an example of development upon gradual lines covering various approaches to the same general answer. Only operational experience would resolve a number of still indeterminate factors particularly in relation to radiation damage which would affect the real amortization period. To test alternative philosophies G2 and G3 incorporate concrete pressure vessels, while EDF 1 and 2 are designed for alloy steel vessels. Whereas 12 months ago it could be assumed that EDF 3 would also use steel it has now been decided to conduct in effect four design studies, for 300 or 400 MW output using either concrete or steel. Table I compares the characteristics of the various plants on the assumption that steel will be adopted. A decision will be made in a few weeks' time, however, on which of the four will be pursued based upon the technical quality and prices submitted by companies tendering for sections of the plant to EDF.

Since April, G2 has been delivering 30 MW to the grid and successful fuel changes of 600-700 kg/day have been executed. Recovery plant has reduced CO_2 loss but the figure still stands at 4%/day. Eight fuel element faults have been observed, most of which stemmed from improper helium filling during manufacture. One failure caused minor contamination of the circuit and the reactor was shut down, but this was due to a cabling fault which resulted in a disconnection of the signal indicating the temperature rise as the channel flow was adjusted. Considerable difficulty has been experienced on the welding of the EDF 1 vessel and the system now adopted is to weld the vertical seams in the vessel courses with preheat to 200°C and then stress relieve at 600°C before allowing the temperature to fall. Three courses are then welded together in the shield, the vessel being maintained meanwhile at 200°C and the whole section is then brought up to 600°C before it is allowed to cool to ambient. The edge preparation has also been changed to a single vee from the original double vee. Before commencing this new technique all plates were returned to the steel-makers for normalizing.

It is important in the French developments to note (a) the change to a hexagonal lattice which has allowed better flattening and (b) the move to hollow fuel rods with a molybdenum addition. In this context it is concluded that a 0.5% Mo alloy is the most satisfactory compromise for radiation resistance and reactivity conservation. Whilst a dramatic change in heat exchanger philosophy is made between G3 and EDF 1—moving from the four large diameter exchangers to the 120 concentric tubes system—for EDF 2 this number has been reduced somewhat and the rating increased: viz. 92 for 170 MW (e) as against 120 for 70 MW (e). It is possible in the EDF stations, that too high a specification has been written for operational pressure and this will be reduced.

Examining the applications of nuclear energy in fields other than producing electricity, attention was drawn to the great

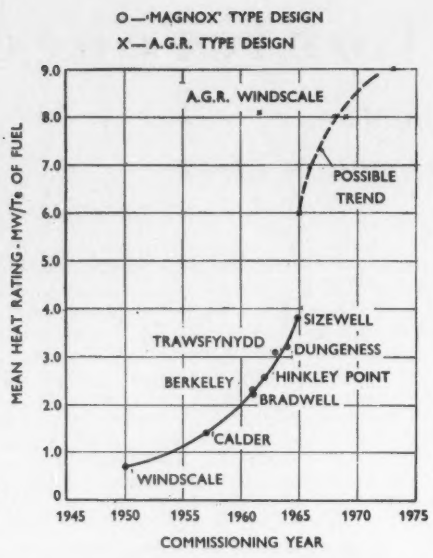


Fig. 1.—Rise in fuel ratings with passage of time.

potential market for process heat generators[5]. The aggregate use of energy in this category in the U.S.A. is considerably greater than electricity and is expected to increase by 65% between 1959 and 1967. Two-thirds of the requirement is in the low temperature range (95-220°C) which should prove an encouraging market for nuclear reactors. Only one reactor, Halden, at present operating, is designed for this purpose (see p. 293). The experience in Sweden[6] is that the economics are no more favourable (and possibly less so) than for electricity generation—although, of course, Sweden has been concerned with district heating which cannot provide the load factor that (say) a large chemical plant can. The application to marine propulsion was also mentioned[7] and to heat and electricity generators in remote areas. The direct use of the radiation from reactors was considered an important long-term prospect,

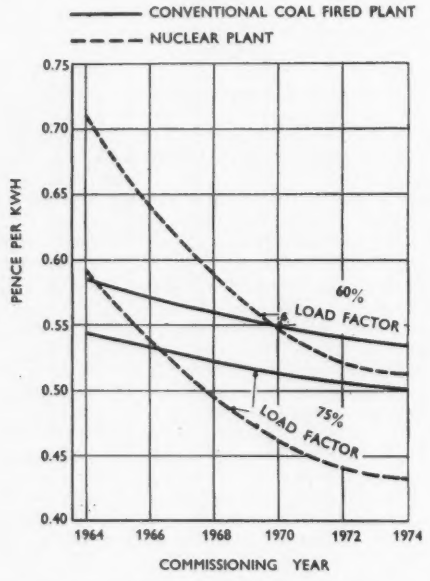


Fig. 2.—Comparison of trends in generating costs —nuclear and coal-fired plants.

reference being made to the Hallam plant where the active sodium coolant is to provide a radiation source of 200,000 rad/h, and an organic moderated reactor proposal in which the reactor coolant absorbing 7-8% of the fission energy is the processed material.

Britain's CEGB had prepared for the conference a most detailed analysis of the cost of nuclear power in the U.K.[8], with which an independent evaluation by the consortia[9] closely agreed, and a similar assessment of the cost trends in conventional plant. For the first time therefore it is possible to quote the capital cost and estimated operating costs of the first British civil stations and—on the assumption that the cost trends will continue—the future economics of the Magnox reactors. The figures for the AGR must be more speculative but are based on a careful and conservative evaluation. Sir Christopher Hinton stated that the CEGB will build an AGR, probably of about 400 MW (e), the inference being that this would be commissioned in '65/66. The reduction in cost/kWh over the years stems partly from the rise in fuel rating (Fig. 1) and partly from increasing coolant gas outlet temperature. If a smooth curve is drawn through the predicted figures (Fig. 2) it is seen that the cross-over point with conventional stations

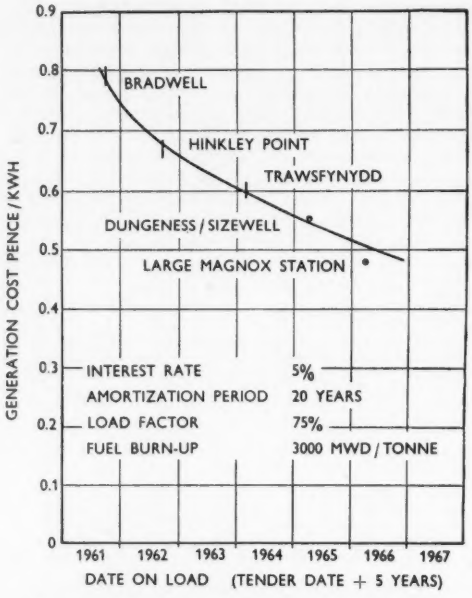


Fig. 3.—Reduction in generating cost with time.

occurs for plant commissioned in 1966 operating at 75% load factor and 1970 if a load factor of 60% is adopted.

A more detailed analysis of the improvements in the Magnox stations shows that in the capital cost reduction of £50/kW from Bradwell to Dungeness, 25% can be ascribed to increase in gas pressure, 25% to straight engineering design advances and 50% to increased size of reactor. Further advances are still practicable, the economic limit to size being about 500 MW (e) per reactor. A two-reactor 1,000 MW (e) station commissioned in 1966 could be expected to be built at a cost of £85/kW$_2$ and would generate power at less than 0.5d/kWh (Fig. 3) at 75% load factor.

Calculations are all based upon a 20-year amortization period originally devised by ascribing 30 years to the generating plant and 15 years to the nuclear (allowing for a replacement reactor unit) until it was appreciated that this would condemn the station to obsolete steam conditions over the second 15 years. The total plant period has therefore been allocated at 20 years as a compromise measure.

To power station engineers the evaluation of various reactor types in terms of fuel conservation[10] makes academic reading in view of the initial conclusion that for many decades availability of low cost or medium cost uranium ores will present

TABLE II

	OMR	ODR	PWR	BWR	GCR
Site	0.5	0.5	0.5	0.5	0.5
Works and building ..	4.0	4.0	4.3	4.6	7.7
Nuclear Plant					
Equipment	10.5	13.1	17.7	17.4	21.6
Installation	3.9	4.2	4.1	3.9	5.6
Conventional Plant					
Equipment	11.5	11.5	12.2	12.2	11.5
Installation	1.4	1.4	1.5	1.5	1.4
Sub-station					
Equipment	1.0	1.0	1.0	1.0	1.0
Installation	0.2	0.2	0.2	0.2	0.2
Replacements	0.8	0.8	1.2	1.2	1.2
Special charges	0.5	5.6	—	—	—
Design	2.5	2.5	2.5	2.5	2.5
General charges	1.3	1.3	1.3	1.3	1.5
First core	2.7	2.7	3.6	6.3	4.0
Total millions of dollars ..	40.8	48.8	50.1	52.6	58.7

no problem. Also some of the assumptions made in the calculations were questioned, for example, the non-recovery of U-235 from natural uranium (the authors were not present to defend their hypotheses). This makes the conclusions somewhat open to question, particularly when it is remembered that only rarely will reactor systems be adopted in any area to the exclusion of all other types rather than as part of a multi-system complex. The desirability from the long-term aspect of breeding is however brought out, this particular technology being pioneered (from the utilities point of view) by the Enrico Fermi plant[1].

Similarly an academic approach to the establishment of a reactor programme[11] which builds up from a natural uranium feed through to the breeder reactors via an enrichment plant and (say) light water reactors or directly through plutonium converters can refer to the main nuclear powers only; it must also ignore outside influences such as military programmes, purchase of materials from abroad, etc. It is important to recognize the necessity for a large ancillary industry capable of manufacturing fuel elements and reprocessing them, and an industry able to construct the plant and undertake development. Each new system becomes more difficult to introduce as it must compete with types at a more advanced stage of development, so that marginal gains are not a sufficient incentive.

Other ancillary but vital aspects of a nuclear programme concern the training of staff, with reference to which details were presented of the steps being taken in the U.K.[12], Spain[13], France[14], and Italy[15], and the provision of proper insurance coverage[16 17 18], not only on a national basis but internationally, otherwise companies will be reluctant to build reactors near national borders. OEEC, IAEA and EURATOM have all prepared draft treaties, that of the OEEC being most advanced. The U.S.A. and U.K. have laws already enacted and on July 1 the Swedish law (based on the OEEC recommendations) comes into force and sets the limit for insurance coverage at the OEEC's minimum figure of $5 million, the indemnity being limited to a 10 year period. The additional state coverage is unlimited and also takes care of the 10-30 year period. Germany and Switzerland are soon to finalize their regulations.

But the installation of nuclear power plants is basically a question of economics plus the gaining of experience. Some financial investment is necessary to educate manufacturing and operating personnel and the argument was advanced that the extent of this could be minimized by installing conventional fuelled superheat systems on to otherwise uneconomic reactors[19 20] which one author[20] claimed would bring the total cost down to below that of a conventional plant—a figure of 5 mill/kWh was quoted. This seemed contrary to the general opinion and would imply that low temperature (process steam, for example) reactors were cheaper than fossil-fuel-fired plant. Alternative methods of energy storage were also proposed[21] and great stress was laid on the necessity for the effect on the economics of existing plant to be considered. Such calculations are, of course, made in the installation of any new plant and may be complex or simple dependent upon how long-term the forecasting purports to be. In any case until nuclear plants take over a major proportion of the base load the influence will be relatively slight.

In Spain, for example, the proportion of the plant that can be bought for pesetas is of the greatest significance[22]. Table II sets out the assessment for five types of reactor. These figures, however, refer to capital cost only and must be allied to the fuel supply. With uranium production indigenous, this would be used as a barter for enriched fuel or fuel elements although a home natural fuel element plant is clearly a simpler solution. Present plans envisage: two reactors of 250 MW in the Madrid area coming into operation in 1968 and 1972, a 250 MW station near Seville in 1970, all in the CENUSA network, together with a 250 MW station during the same period at Sobron near Burgos in the NUCLENOR network. Meanwhile the Junta is completing plans for a small experimental organic moderated plant. This will be a 30 MW (e) dual purpose heavy-water-moderated organic-cooled reactor with a central, separately cooled, channel for fuel element testing. Preliminary study is complete; firm estimation of foreign currency costs in preparation. Provided sanction for foreign expenditure is given, plant could be ready in 1964. By 1975 the installed capacity can be expected to be in the region of 1,800 MW.

India, somewhat less restricted for foreign capital, requires plant over a vast area where local conditions vary widely. The West Coast hydro resources will be developed at high speed and thermal stations will be built at the pit heads over the brown coal deposits (30% ash) in the north; high-grade coal will be reserved for ore processing and similar chemical demands. The south will need nuclear stations where they will be already economic. It has now been decided to make the Bombay station a 2 by 150 MW plant fuelled with natural uranium, either graphite or heavy-water moderated and international tenders will be sought before mid-summer, from the western world. The plant will operate in an area of 70% load factor. Negotiations are proceeding with the U.S.S.R. for collaboration on small (15-25 MW) water-cooled graphite moderated plants with integral superheat and with the U.S.A. for an enriched uranium water reactor of medium power.

The five-year plan for 1965-70 envisages 1,000-2,000 MW of nuclear plant being installed and from 1965 onwards a nuclear installation corresponding to 25% of the total new capacity.

This sectional meeting of the World Power Conference was particularly well attended although the U.S.S.R. delegation was small and no reference was made to their nuclear activities. Highly organized and held in a building ideally equipped for the purpose—the Instituto Nacional de Industria—the conference provided great scope for informal discussion in addition to the formal sessions. Some of the comments in the above summary stem from these extra-mural conversations.

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5 Low-Power Nuclear Reactors for Producing Electricity and Heat: G. E. Villar (E).
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7 Installation of Nuclear Reactors in Merchant Ships with Atomic Propulsion: G. Cesoni (I).
8 The Economics of Nuclear Power in Great Britain: Sir Christopher Hinton, F. H. S. Brown and L. Rotherham (GB).
9 The Technical and Economic Development of the Gas-cooled Reactor: R. D. Vaughan (GB).
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11 The Factors Influencing the Development of a Nuclear Power Programme: H. Cartwright (GB).
12 The Training of Operating Staff for the first British Civil Nuclear Power Stations: G. T. Shepherd and J. C. C. Stewart (GB).
13 The Training of Atomic Technicians at Different Levels in Spain: Armando Duran Miranda (E).
14 Policy and Achievement of the French Atomic Energy Board in the Training of Staff: J. Debiesse (F).
15 Installation of Nuclear Reactors on an Industrial Scale: G. Cuocolo (I).
16 Problems Arising out of the Insurance of Land-based Nuclear Projects: A. G. M. Batten and G. F. Bullock (GB).
17 Problems of Security and Insurance in Atomic Centres and Plants: Their Legal Aspects: Ignacio Munoz Rojas (E).
18 Coverage of Nuclear Risks. A Question of Vital Importance for Operators and Suppliers of Reactors: M. Scheirwimmer (D).
19 The Economic Use of Conventional and Nuclear Fuel in an Electricity Supply System: F. A. P. M. Theunissen (NL).
20 Improvement of Load Characteristics of Nuclear Power Plants by Electroheat: Otto Herbatscheck (A).
21 Possibilities for Spanish Industry in the Construction of Nuclear Power Stations: Haim Mac Veigh y Alfos (E) (I).
22 Incorporation of Atomic-produced Energy into the Spanish Electricity Supply and its Development: Havier Molina and Francisco Pascual Martinez (E).

NUKEM: German Fuel Fabrication Facility

Nuclear fuel manufacturing consortia at Wolfgang bei Hanau, Frankfurt

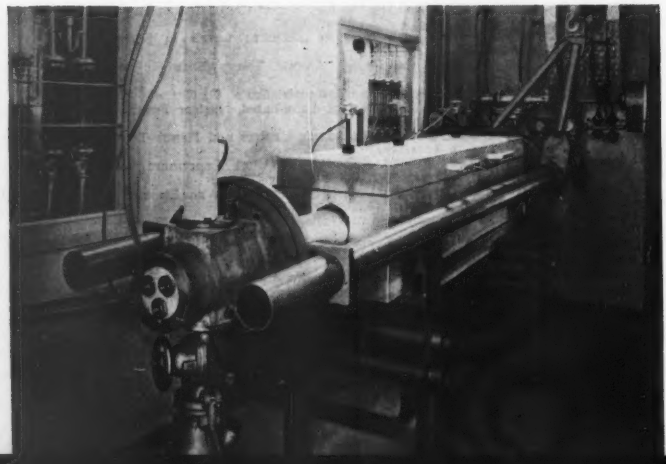
THE association of Germany's DEGUSSA (Deutsche Gold- und Silber-Scheideanstalt vormals Roessler) and Britain's Rio Tinto Management Services and the U.S. company Mallinckrodt Chemical Works, into the concern NUKEM (Nuklear-Chemi und-Metallurgie Gesellschaft) for the manufacture of nuclear fuels, presents an interesting international combination. Although production will be limited for the time being, the research and development work undertaken will undoubtedly be of valuable service to the growing nuclear industry in Germany and Europe.

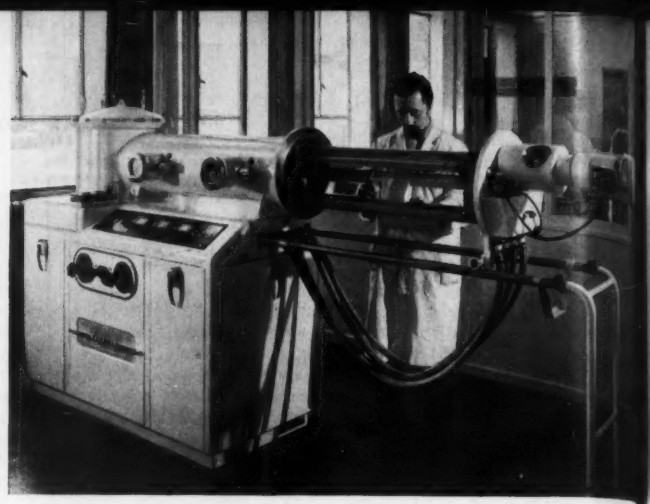
NUKEM have taken over the complete nuclear division of DEGUSSA, including staff, patents, contracts, know-how, stock and all fabrication and research facilities. These include a pilot plant for nuclear pure uranium metal and uranium dioxide with a capacity of about 50 tons per year.

The company will act as agent in Europe between customers and Mallinckrodt for the conversion of enriched materials and also as agents for the furnace fabrication division of DEGUSSA for the sale and supply of furnaces and installations for nuclear applications. The present production programme includes: reactor grade metals like uranium, thorium; reactor grade compounds of these elements; metallic fuel elements for gas- and water-cooled heterogeneous reactors; ceramic fuel elements for gas- and water-cooled heterogenous reactors, and equipment for the reduction and fabrication of the above-mentioned materials.

Existing contracts include the completion of 10 tons of aluminium clad natural uranium elements for FR-2, the 12 MW heavy-water-type research reactor at Karlsruhe; the manufacture of 20% enriched, picture-frame-type Argonaut elements for Kernreaktor-Gesellschaft Karlsruhe and others. In addition manufacturing facilities for "pebble" elements for the BBC/Krupp high-temperature gas-cooled reactor are under construction.

A rotary tube hydrofluorination furnace.





The high vacuum metallizing apparatus.

Research and Development

The research and development work undertaken by the company includes the completion of the BBC/Krupp fuel elements; research on aluminium clad thorium breeding elements and work on Zircaloy clad natural uranium elements for a 50 MWe pressurized heavy-water reactor. NUKEM also hold various contracts for fuel and fuel element development with the Federal Ministry for Atomic Energy as well as with Euratom and other private concerns. It would appear that the major companies manufacturing reactors in Germany will use NUKEM for research work and manufacture of fuel elements and it is expected that the larger portion of the work undertaken by the company for the next few years will be mainly research and development.

It is interesting to note that the history of nuclear fuel fabrication in the DEGUSSA organization goes back to 1940 with the production of uranium metal from pitchblende. This work helped in the entry at an early stage of the industrial furnaces division of DEGUSSA in the supply of plant, mainly furnaces, for uranium refining plants, and today close relations exist in this field with several countries.

An important piece of equipment is the batch type sintering furnace evacuated for operation under hydrogen atmosphere and resistance heated with molybdenum elements. The furnaces are manufactured in three different sizes and have been supplied to several countries throughout the world. These include six to the U.K.AEA; four to Sweden; one each to Denmark, Belgium, Spain, Japan and Italy.

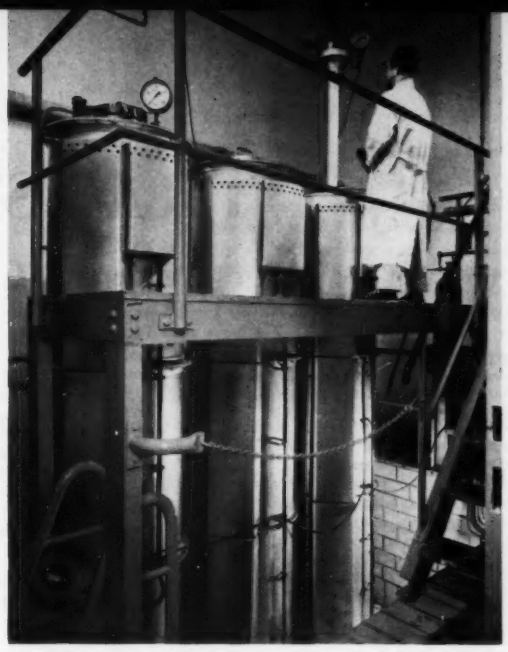
Most production equipment is geared to work automatically. This includes a design by AB Atomenergi of Sweden for rotary hydrofluorination and reduction furnaces. The former is a rotary tube furnace for the hydrofluorination of UO_2 with dehydrated hydrofluoric acid. Operational temperature of the furnaces is 550°C and the capacity is approximately 40 tons per year in the pilot type. One of the main features of this furnace is the absolute tightness of the seals against any penetration of hydrofluoric acid and the high quality of the UF_4 due to favourable reaction conditions in the furnace.

Reduction furnaces of similar design have also been developed. These serve for the reduction of calcinated UO_3 or U_3O_8 to UO_2. The design is basically the same as for the hydrofluorination furnaces except for simpler seals; hydrogen or cracked gas is used as the reaction gas. Operation temperatures of these furnaces can be as high as 900°C and although the pilot type has been designed for 35 tons a year types capable of 300 tons a year can be manufactured.

An impressive piece of equipment is a high vacuum metallizing plant. This apparatus serves for the evaporation of brazing metals under high vacuum for condensation on to the surface of metal U rods under vacuum. In operation, six rods are chucked in a planetary gear at a time and rotated while the brazing metals, lying in molybdenum vessels, are resistance heated and evaporated. Before the evaporation takes place the remaining humidity on the surface of the rods is removed by a glow discharge device. The thickness of the bonding layer for the FR-2 elements, for example, is between 18 and 24 microns and accurate measurements can be made by the resistance of a quartz-rod, simultaneously covered by the bonding metal.

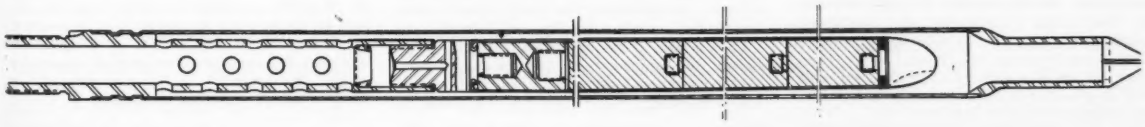
The remainder of the production facilities are modern and fairly standard. Uranium extraction is done by normal reciprocating columns. Extrusion of uranium alloys in the gamma phase is done with protective salt cladding and a high stability under thermal cycling can be reached. Sintering is carried out in a batch type furnace evacuable prior to the operation under hydrogen atmosphere and resistance heated with molybdenum elements, and oxide pellets can be made stoichiometric and non-stoichiometric with densities of more than 10.6 to small tolerances.

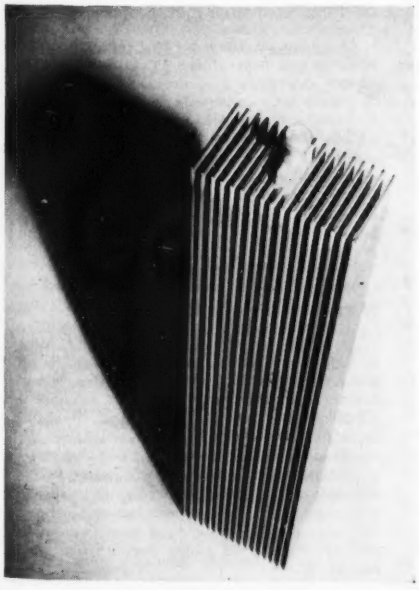
The facilities also include two autoclaves, an air type for bonding processes and a water autoclave for corrosion tests, high vacuum reduction furnaces and a big electron beam melting apparatus working in three shifts. Bonding is effected at a temperature of about 400°C under pressure and the corrosion tests are made in pressurized water at temperatures of about 200°C and a pressure of 18 atmospheres. Ultrasonic methods are used in the determination of grain size and inspection of the bond, helium leak detection equipment is used for extruded can materials and automatic recorders are employed for final checking of elements. An automatic arc welding process is used for sealing tubular cans. A vacuum furnace for the reduction of thorium is also part of the manufacturing facilities.



Bonding, material testing and leak detection high pressure autoclaves.

NUKEM is a new name for an old-established nuclear fuel research and fabrication facility. The company is in a position to do research work for, and manufacture, metallic, ceramic and cermet fuel elements, enriched uranium materials and conversion services, reactor fuel elements and plant and equipment for the production and processing of fuel materials and fuel elements. With a staff of 150 and the liaison between DEGUSSA'S industrial furnace division, Mallinckrodt and Rio Tinto, it would appear that there are few limitations as to the nature of work this company can undertake.





(Top) A sectional drawing of the FR-2 aluminium clad, natural uranium element. (Right) The completed elements for FR-2, a 12 MW heavy - water research reactor.

(Left) A seventeen plate cold extruded Argonaut-type element.

TRANSLATIONS

A Résumé of Principal Articles

L'Agence Européenne d'Energie Nucléaire

En coordonnant les activités des différents pays de l'O.E.C.E. dans le domaine nucléaire, l'Agence européenne d'energie nucléaire joue un rôle essentiel en stimulant l'utilisation pacifique de l'énergie nucléaire.

L'agence est responsable de trois projets internationaux: le réacteur d'HALDEN à eau lourde bouillante, l'usine de traitement des combustibles nucléaires de l'EUROCHEMIC et le Projet DRAGON. En outre, elle permet la discussion sur une base internationale de problèmes légaux ou sociaux.

Le Réacteur d'Halden

Une description technique et une perspective à grande échelle du réacteur d'Halden ont paru dans le numero de Mars 1959 de Nuclear Engineering. Le présent article rend compte des travaux exécutés depuis la mise en route du réacteur en Juin 1959. Il résume en outre le programme des travaux futurs dans le cadre de l'accord international relatif à ce projet.

Eurochemic Organization

La compagnie EUROCHEMIC formée par les états membres de l'O.E.C.E., pour le traitement de combustibles irradiés, fait l'objet de statuts tout-à-fait particuliers. Ceux-cis sont le fruit de la collaboration internationale. Le siège de la compagnie est à Mol, le centre belge de recherche nucléaire. Les actions de la compagnies sont détenues par les gouvernements des trieze pays participants; des entreprises privées de chaque pays ont la faculté de s'intéresser financièrement au projet. Apres deux années de travaux préparatoires, la compagnie vient de démarrer la construction de sa première usine pilote.

La Capacité de l'Installation d'Eurochemic

Le problème qui se posait aux techniciens d'EUROCHEMIC était complexe. Il s'agissait de fixer la capacité de l'installation nécessaire en première urgence. La production de l'usine-pilote a été limitée à 350g/jour, les éléments de combustible traités étant à base d'uranium naturel gaîné d'aluminium ou de magnésium. Le cycle de traitement envisagé est du type Purex en deux étapes. L'usine proprement dite sera construite l'année prochaine; elle fonctionnera à partir de 1964.

Le Projet Dragon

Le troisième projet nucléaire de l'O.E.C.E., le réacteur Dragon à gaz à haute température, d'une puissance de 20 MW est en cours de construction à Winfrith (Dorset), en Angleterre. Mr. Rennie, directeur general, décrit les grandes lignes de l'organisation du team chargé de la conception et de la construction de ce réacteur qui est d'un type particulièrement intéressant. L'étude de Mr. Rennie est suivie d'une brève analyse des objectifs du projet et d'une description générale des parties principales de l'installation.

Die europäische Verwaltung für Kernenenergie OEEC.

Durch Gleichschaltung der Wirksamkeit der OEEC-Länder, spielt die europäische Behörde für Kernenenergie eine wichtige Rolle zur Förderung der Friedensverwertung von Kernenenergie. Die Verwaltung ist für drei gemeinsame Unternehmungen verantwortlich: den Reaktor "Halden" mit kochendem Schwerwasser; die Aufbereitungs-Anlage "Eurochemic" sowie das Projekt "Dragon". Ausserdem stellt sie das Forum dar zur Erörterung von Problemen der Gesetzgebung sowie sozialer Ordnung dar.

Reaktor "Halden"

Eine technische Beschreibung und eine grosse Zeichnung in Perspektive der Reaktor "Halden" wurden in "Nuclear Engineering" im März 1959 veröffentlicht. Dieser Aufsatz berichtet über die ausgeführten Arbeiten seitdem der kritische Zustand im Juni 1959 erreicht wurde. Auch gibt er eine Zusammenfassung der Programme, das innerhalb der internationalen Projekt auszuführen ist.

Die Organisation "Eurochemic"

Die Körperschaft "Eurochemic" welche seitens der Mitglieder-Länder der OEEC zum Zwecke der Aufarbeitung von bestrahlten Spaltstoffen aufgestellt wurde, erfreut sich einer Konstitution, welche einigermassen ungewöhnlich ist. Sie ist prinzipiell das Ergebnis internationaler Zusammenwirkung, wobei der Hauptsitz sich in Mol, dem Zentrum belgischer Kernforschung, befindet. Anteile an der Gesellschaft befinden sich in den Händen der Regierungen von 13 verschiedenen Ländern; private Gesellschaften in jedem Lande ist Gelegenheit geboten worden, ein Interesse an "Eurochemic" zu erwerben. Nach zwei Jahren von Forschungsarbeiten hat die Körperschaft soeben mit der Herstellung der ersten Versuchs-Anlage zur Produktion begonnen.

Die technische Aufgabe der "Eurochemic"

Der Konstruktionsstab der "Eurochemic" hatte sich mit einem Problem erheblicher Grösse zu befassen, als es galt, eine Entscheidung zu treffen über das Ausmass der im ersten Stadium zu bauenden Anlage. Die Grösse der Versuchsanlage ist auf eine Nennleistung von 350 kg pro Tag für natürliche Uranelemente in Aluminium—oder Magnesium-Hülsen beschränkt worden. Das grundlegende Fliessprogramm, das angenommen wurde, ist von der Art "Purex" mit zwei Kreisläufen; die Anlage selber wird im Laufe des nächsten Jahres gebaut; effektiver Betrieb ist für 1964 in Aussicht genommen.

Projekt "Dragon"

Dieses ist der dritte Bauentwurf für Kernanlagen der OEEC. Der in Aussicht genommene Reaktor von 20 MW für hohe Temperatur und Gaskühlung, welcher als "Dragon" bezeichnet ist, wird gegenwärtig in Winfrith in der Grafschaft Dorset in England aufgestellt. Der Hauptleiter, Mr. Rennie, gibt eine Uebersicht über die Organisation des Stabes von Mitarbeitern, denen die Konstruktion und Ausführung dieses Reaktors einer Art von aussergewöhnlichem Interesse obliegt. Den Erörterungen von Mr. Rennie folgt eine kurze Erklärung über die Zwecke dieses besonderen Objektes, sowie eine allgemeine Beschreibung der Hauptmerkmale dieses Reaktors.

La Agencia de Energia Nuclear Europea—O.E.E.C.

Mediante la coordinación de las actividades de los paises de la O.E.E.C., la Agencia de Energia Nuclear Europea juega un papel vital en promover los usos pacificos de la energia nuclear. Es responsable de tres empresas conjuntas: el reactor de agua pesada hirviente HALDEN; la planta de procesado EUROCHEMIC y el proyecto DRAGON. Además, ofrece el foro necesario para la discusión de problemas legislativos y sociales.

Reactor Halden

Una descripción técnica y un dibujo grande en perspectiva del reactor Halden fueron publicados en Nuclear Engineering en marzo de 1959. Este artículo da cuenta de las labores llevadas a cabo desde que se alcanzó la criticalidad en junio de 1959. También hacen un sumario del programa a ser llevado a cabo dentro del proyecto internacional.

La Organización Eurochemic

La Compañia EUROCHEMIC que ha sido establecida por los paises miembros de la O.E.E.C. para el reprocesado de combustibles irradiados goza de una constitución que es, por asi decirlo, única en su género. Es principalmente el resultado de colaboración internacional, estando la casa matriz en Mol, el centro de las investigaciones nucleares belgas. Las acciones de la Compañia están en manos de los Gobiernos de 13 paises; a compañias particulares en cada pais se les ha dado la oportunidad de adquirir un interés en EUROCHEMIC. Después de dos años de labores exploratorias la Compañia acaba de comenzar la construcción de su primera planta piloto de producción.

La Tarea Tecnica de Eurochemic

El equipo de diseñado de EUROCHEMIC tuvieron que hacer frente a un problema de alguna envergadura al decidir qué capacidad de planta sería construida en la primera etapa. El tamaño de la planta piloto ha sido limitado a una capacidad nominal de 350 Kg/dia elementos de aluminio o de uranio natural envasado en magnesio. La hoja básica de flujo adoptada es del tipo "purex" con dos ciclos. La planta misma será construida el año próximo y la operación efectiva de ella está programada para 1964.

El Proyecto Dragon

El tercero de los proyectos de O.E.E.C., el proyectado reactor enfriado por gas y de alta temperatura de 20 MW se está actualmente construyendo en Winfrith en Dorset, Inglaterra. El dirigente principal, Mr. Rennie, bosqueja la organización del equipo responsable del diseñado y la construcción de este tipo excepcionalmente interesante de reactor. La discusión de Mr. Rennie va seguida de una breve declaración de los objetivos perseguidos por este proyecto, juntamente con una descripción general de las principales características del reactor.

TRANSLATIONS—A Résumé of Principal Articles (Contd.)

Le Système de Contrôle du Réacteur Dragon

Il est constitué par 24 barres de contrôle contenant des grains de carbure de bore. Ces barres peuvent être insérées dans des trous de trouvant au sein du réflecteur sur le pourtour du coeur. Lorsque toutes les barres sont insérées à fond, un écran virtuellement continus est constitué et tous les neutrons sortant de coeur sont absorbés. L'article décrit les principes à la base de la conception, de la réalisation de l'utilisation et de l'entretien des mécanismes de commande des barres de contrôle.

Les Eléments de Combustibles du Réacteur Dragon

De nombreuses investigations relatives au type d'éléments de combustible requis pour le réacteur Dragon ont été dejà entreprises. Plusieurs expériences ont été rendues possible par l'utilisation de ZENITH, un réacteur de recherche d'énergie nulle. L'article décrit les nombreux types d'éléments de combustible différents qui ont été proposés. La dernière revision qui sera probablement utilisée est étudiée en détail.

Les Principales Caracteristiques du Graphite Utiles pour le Réacteur Dragon

Le graphite devra être complètement imperméable. R. A. Huddle, un expert en la matière, décrit les différents procédés permettant d'obtenir du graphite imperméable. Il donne un aperçu de la méthode de production probable du graphite requis pour le réacteur Dragon.

La Conférence Mondiale de l'Energie

La conférence de cette année ne s'étendra pas à tous les domaines considérés habituellement. Ce pendant, quelques rapports relatifs à la production d'énergie nucléaire et aux recherches qui s'y attachent seront présentés à Madrid par diverses personnalités éminentes. Les rapports les plus importants sont analysés par notre correspondant.

NUKEM—Une Installation Allemande pour la Fabrication d'Eléments de Combustible

NUKEM—(Nuklear Chemie und Metallurgie Gesellschaft), une compagnie qui va se spécialiser dans la fabrication d'éléments de combustible nucléaire a été constituée par les trois groupements suivants: Degussa (Allemagne), Mallinckrodt (Etats-Unis), Rio Tinto (Grande Bretagne). NUKEM a repris complètement la division nucléaire de Degussa à Wolfgang près de Hanau y compris les brevets, les marchés en cours, les cadres et les installations.

La nouvelle compagnie sera l'agente des Commissariat américain à l'énergie atomique pour la vont de combustible enrichi. En outre elle représentera les fours produits par une division spéciale de Degussa, I.O.B.

Il est prévu que le principal de l'activité de NUKEM aura trait à la recherche pendant un certain temps. Des accords ont déja été conclus avec plusieurs entreprises nucléaire allemandes importantes.

Steueranlage " Dragon "

Die Steuervorrichtung für die Anlage " Dragon " umfasst 24 Absorptionsstäbe enthaltend Körner von Borkarbid, welche in Löcher im Spiegel nahe dem Rande des Kernes abzusenken sind. Wenn sämtliche Stangen herabgelassen sind, wird ein praktisch massiver Vorhang geschaffen und alle den Kern verlassenden Neutronen sind verloren. Dieser Artikel beschreibt die Konstruktions-Philosophie auf welcher Entwurf, Herstellung, Betrieb und Instandhaltung des Regelstabgetriebes aufgebaut ist.

Spaltstoff—Elemente für " Dragon "

Ein erheblicher Aufwand an Forschungsarbeit ist bereits über die Art von Brennstoffelementen geleistet worden, die in der Anlage " Dragon " zur Verwendung gelangen sollen. Zahlreiche dieser Versuche wurden auf dem Nullpunkts-Energie-Aggregat ausgeführt, welches unter dem Namen von " Zenith " bekannt ist. Dieser Artikel beschreibt die vielen verschiedenen Arten von Elementen, die in Betracht gezogen wurden und beschreibt ausführlich die neueste Ausführungsart, die höchstwahrscheinlich zur Anwendung gelangen dürfte.

Spezifikation für Graphit für Projekt " Dragon "

Ein bedeutender Faktor in der Konstruktion der Anlage " Dragon " ist das Erfordernis nach einem gänzlich undurchlässigen Graphit. R. A. Huddle, ein Sachverständiger in diesem Gebiete, beschreibt die verschiedenen Wege, auf welchen undurchlässiger Graphit erzielt werden kann und kennzeichnet das voraussichliche Verfahren zur Herstellung des erforderlichen Graphites für das Projekt " Dragon."

Welt Kraft Konferenz

Wiewohl die Zusammenkunft dieses Jahres nur ein Teilgebiet umfasst, so wurden eine Anzahl von Vorträgen über Entwicklungen in Kernforschung und Krafterzeugung seitens einiger der führenden Fachleute der Welt kürzlich in Madrid gehalten. Die bedeutenderen dieser Vorlesungen sind durch unseren eigenen Korrespondenten zusammengefasst.

NUKEM—(Deutsche Anlage zur Herstellung von Spaltstoff)

Ein Konsortium von drei Unternehmungen, u.zw. die Degussa in Deutschland, Mallinckrodt in der U.S.A. und die englische Gesellschaft Rio Tinto, hat sich zur Gründung einer Körperschaft zusammengeschlossen, der " NUKEM " (Nuklear-Chemie und Metallurgie-Gesellschaft) u.z. zur Erzeugung von Kernbrennstoffen. Die neue Unternehmung hat die komplette Kernabteilung der Degussa in Wolfgang bei Hanau übernommen. Hierbei sind Patente, Abkommen, Herstellungskenntnisse (" know-how ") sowohl wie die Erzeugungsanlagen inbegriffen.

Die Gesellschaft wird ebenfalls als Vertreter zwischen Kunden und der amerikanischen A.E.C. zur Lieferung von angereicherten Werkstoffen auftreten, sowie auch als Absatzvertreter für Oefen, die seitens der Ofenherstellungs-Abteilung der Degussa, I.O.B. erzeugt werden.

Es wird angenommen, dass die seitens der Gesellschaft geleistete Arbeit während einiger Zeit hauptsächlich aus Forschung bestehen wird und es sind bereits Abkommen mit verschiedenen grösseren deutschen Kernkraft-Unternehmungen geschlossen worden.

El Sistema de Control de Dragon

El sistema de control de DRAGON provee que hayan 24 varillas absorbentes conteniendo gránulos de borón-carburo a ser bajadas dentro de orificios en el reflector cerca del borde del núcleo. Con todas las varillas bajadas se forma una cortina virtualmente sólida y todos los neutrones que salen del núcleo se pierden. Este articulo describe la filosofia ingenieril que respalda el diseño, fabricación, operación y mantenimiento de los mecanismos de varillas de control.

Los Elementos de Combustible de Dragon

Se ha llevado ya a cabo una cantidad considerable de investigaciones sobre el tipo de elementos de combustible que se han de usar en DRAGON. Muchos de estos experimentos fueron llevados a cabo sobre el conjunto de energia cero conocido como ZENITH. Este articulo describe los muchos distintos tipos de elementos que fueron considerados y describe también en detalle la última versión que es la más probable a ser efectivamente empleada.

Dragon: Especificacién Del Grafito

Una importante caracteristica del diseño de DRAGON es la necesidad de tener un grafito completamente impermeable. R. A. Huddle, una autoridad en la materia, discute los diversos modos en que se puede obtener grafito impermeable y bosqueja el método probable de producir el grafito que se necesita para el proyecto DRAGON.

Conferencía Mundial de Energia

Aunque la Reunión de este año es solamente una discusión seccional, fueron presetados recientemente en Madrid por algunas de las principales autoridades Mundiales diversos documentos relacionados con investigaciones de energia nuclear y la producción de fuerza motriz. Nuestro propio corresponsal hace un sumario de las más importantes de estas disertaciones.

NUKEM—Planta Alemana de Fabricacion de Combustible

Un consorcio formado por tres entidades, Degussa de Alemania, Mallinckrodt de los E.E. U.U. y la compañia Rio Tinto de la Gran Bretaña, se han combinado para formar una Compañía–NUKEM, (Nuklear-Chemie und Metallurgie Gesselschaft), para la fabricación de combustibles nucleares. La nueva Compañia se ha hecho cargo de la entera división nuclear de Degussa en Wolfgang bei Hanau. Esto incluye patentes, contratos, " know-how " (conocimientos periciales) asi como las facilidades de fabricación.

La Compañía también va a actuar como agentes entre clientes y la AEC de los E.E. U.U. para el suministro de materiales enriquecidos y como agentes de ventas de hornos hechos por la división manufacturera de hornos de Degussa, I.O.B.

Se espera que la mayor parte del trabajo que haga la Compañía será por el lado de investigaciones durante algún tiempo y ya existen acuerdos con varias grandes entidades nucleares alemanas.

Personal

Dr. G. B. Cook.

Sir Kenneth Hague.

Mr. G. H. Doust.

Dr. G. W. Oyler.

Appointments

Mr. B. S. Smith as head of the isotope research division of AERE, Harwell.

Mr. W. L. Fraser as first president of Babcock and Wilcox; **Sir Kenneth Hague** as chairman of the board and **Sir Reginald Verdon Smith** as deputy.

Mr. R. Langford and **Mr. I. H. Phillipps** to the board of Humphreys and Glasgow.

Mr. G. H. Doust as general manager of Plessey International.

Mr. W. E. Bardgett as president of the Institution of Metallurgists.

Dr. P. R. Howard as head of the high-voltage laboratories of the Central Elecricity Research Laboratories.

Mr. E. W. A. Richards and **Mr. A. H. Woodley** to the board of Keith Blackman.

Mr. S. Baker as director in charge of production of Davy and United Engineering.

Mr. F. Bastow as managing director of Dowty Seals; **Mr. C. N. King** to the board of Dowty Hydraulic Units.

Mr. C. J. George as deputy commercial and development adviser to the Electricity Council.

Mr. J. W. Law to the board of Powell Duffryn Technical Services.

Mr. A. S. Beaumont as secretary to Walter Somers and Walter Somers (Materials Handling).

Mr. J. L. Orme as deputy chief engineer of the London, Eastern and Southern areas of G.E.C.

Mr. E. H. Stagg, Mr. G. W. Heslett and **Mr. M. W. Zublin** as joint managing directors of Sulzer Bros. and Hathorn, Davey and Co.

Mr. S. Farrer to the board of British Furnaces and **Mr. F. Bonsall** as managing director.

Mr. P. W. Faulkner as deputy managing director of Rank-Xerox.

Mr. N. C. Fraser as chairman of the British Chemical Plant Manufacturers Association.

Mr. N. Fenwick as sales promotion manager of Pye.

Mr. G. Robbins to the technical sales staff of Aveley Electric.

Mr. R. E. Selff.

Mr. G. Robbins.

Sir Walter Worboys as chairman of BTR Industries; **Mr. F. S. Lloyd** as purchasing officer.

Mr. R. A. Moir as chairman and **Mr. W. F. Oakley** as vice-chairman of the Telecommunication Engineering and Manufacturing Association.

Sir Geoffrey Bourne as director-general of the Aluminium Development Association.

Overseas

Mr. J. N. McArthur to the board of AMF.

Dr. G. W. Oyler as head of the welding research and development department of M. and C. Nuclear.

Dr. G. B. Cook of the U.K. as chief chemist of the IAEA.

Dr. W. M. Breazeale as nuclear adviser to **Vice-Admiral A. C. Richmond,** chairman of the U.S. delegation to the International Conference for the Safety of Life at Sea.

Mr. J. C. McMahon as marketing research manager of AMF's atomic division.

Mr. P. W. McDaniel as director of the research division, U.S.AEC.

Mr. J. L. Wilson as manager of the U.S.AEC's Lockland Aircraft Reactors Operations office.

Prof. V. S. Emelyanov as chairman of the U.S.S.R. nuclear energy committee. Prof. Emelyanov was formerly head of the central office for nuclear energy.

Mr. R. E. Selff as manager of the nuclear division of Turco Products, Calf.

Mr. L. D. Low as director of the U.S. AEC's division of compliance.

Awards

Mr. J. B. Adams, director general, ad interim, of the European Organization for Nuclear Research, an honorary degree by the University of Geneva.

Obituary

Nuclear Engineering regret to report the death of the following:—

Sir Oswald A. Scott, chairman of Detel Products on May 19.

Resignations

Mr. J. F. Floberg and **Mr. J. H. Williams,** commissioners, from the U.S.AEC.

Dr. W. Teller as director of the Livermore Laboratory of the Lawrence Radiation Laboratory.

Mr. R. V. Ely from the boards of Lancashire Dynamo Holdings, Foster Transformers and Foster Electrical Supplies.

Retirements

Mr. R. Fairey from the board of directors and as vice-chairman of The Fairey Company.

Mr. R. M. Atkinson as managing director of Sulzer Bros. and of Hathorn Davey and Company.

Mr. R. Miles as chairman and managing director of Head Wrightson.

Air Commodore W. Helmore as director-general of the Aluminium Development Association.

Tours

Sir Roger Makins, chairman of the U.K.AEA, of the U.S. and Canada for official talks during June.

Mr. J. L. Kuran, vice president of Nuclear Chicago on a round-the-world tour of nuclear establishments.

Mr. J. J. Hill of the National Physical Laboratory of the U.S.S.R. for a fortnight's lecture tour.

Senator Spooner of Australia of nuclear establishments in the U.K., France, the U.S. and Canada to study trends in nuclear energy utilization.

Birthday Honours

KNIGHTS

Dr. B. F. J. Schonland, director, research group, Harwell.

Mr. W. H. McFadzean, chairman BICC and president of the Federation of British Industries.

Mr. G. B. B. McIvor Sutherland, director of the National Physical Laboratory.

Mr. F. Bower, president of the Association of British Chambers of Commerce.

K.B.E.

Mr. C. R. King, chairman of the Electricity Council.

C.B.E.

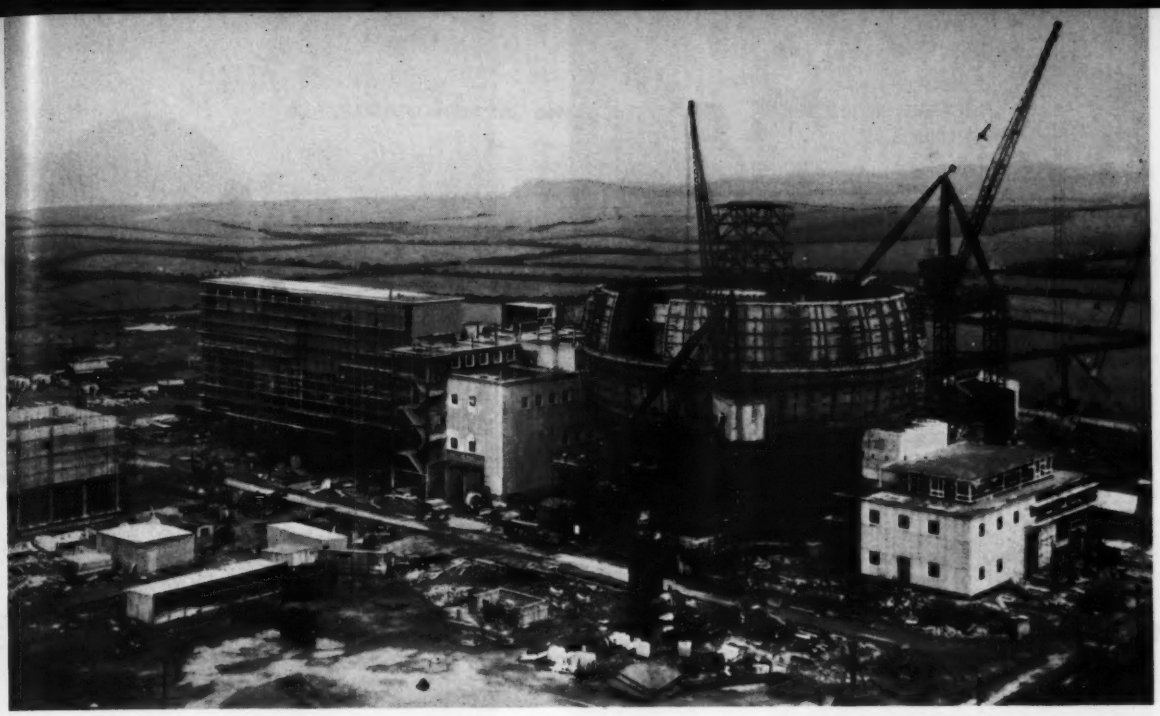
Mr. T. E. Allibone, director of the research laboratories of A.E.I.

O.B.E.

Mr. F. H. Saniter, director of research of the United Steel Companies.

Dr. B. F. J. Schonland.

Mr. W. H. McFadzean.



The latest view of the AGR at Windscale which is due to begin operating early next year.

World News

International

THE ANNUAL REPORT of the IAEA to the United Nations Economic and Social Council states that the need for nuclear power remains as great as ever. The report also states that the deferment of short-term expectations is probably because earlier appraisals underestimated the seriousness of the technological problems and were unduly influenced by transient economic and political factors.

A TEAM of U.S. scientists in high energy physics has paid a visit to the IAEA in order to familiarize themselves with the Agency's work. The team recently visited the U.S.S.R.

THE WORK PROGRAMME and budget of the IAEA was discussed at a meeting of the Board of Governors during June. The proposals and programme formulated by the Board will be passed to the General Assembly for approval in September.

A RELATIONSHIP AGREEMENT between the IAEA and the European Nuclear Energy Agency of OEEC will be considered by the Board of Governors of the IAEA before submission to the General Assembly.

A COMMITTEE have selected 131 scientific papers from 18 different countries to be presented at the Conference on Radioisotopes in the Physical Sciences and Industry, to be held in Copenhagen from September 6-17. The conference is being held by the IAEA in conjunction with UNESCO. It is expected that more than 150 papers will finally be selected.

IN HIS CLOSING REMARKS at the international symposium on fuel element fabrication with special emphasis on cladding material, the Director General, Mr. Sterling Cole, said that three conclusions could be drawn from the meeting. First, that considerable interest was demonstrated in the use of zirconium alloys and graphite as cladding materials; secondly, the importance of the studies of corrosion and radiation damage and thirdly the importance of the development of new types of fuel elements and of novel methods of fabrication in achieving economically competitive nuclear power.

MORE THAN 200 scientists, representing 28 countries, met in Vienna during June at a symposium on radiation dosimetry organized by the IAEA. The symposium was held mainly for a discussion on the various methods used throughout the world.

U.K.

THE LAUNCHING of the *Dreadnought* on October 21 will be performed by Her Majesty The Queen, according to an announcement by Lord Carrington, First Lord of the Admiralty. Lord Carrington also announced that plans for the construction of a second nuclear submarine were well under way and that a contract would be placed within the next few months.

IT WAS DECIDED in London, at the International Conference on Safety of Life at Sea, to approve new laws for nuclear-powered ships using foreign ports.

THE FIFTH COURSE on the control and instrumentation of reactors will be held at the Harwell Reactor School from September 12-23 and will be open to British and overseas students. Visits will also be held to zero energy and high flux research reactors.

A SITE PROGRESS REPORT on Trawsfynydd states that the walls of No. 1 reactor are beginning to take shape and that the bases are being formed for the gas circulators. Work has now also started on the centre ring of the 65-ft-high outer shield.

THE WORKING MODEL of an apparatus used for controlled fusion research, MINNIE, has been presented by the AEA to the Royal College of Science and Technology, Glasgow. The device has a maximum power of 5 kV, a maximum stored energy of 2,000 joules and an inductance of 2.2 millimicro-henrys.

AN EXHIBITION on the reasons for selecting a site in Kent for the construction of a nuclear power station was held in three towns in Kent during June.

Australia

A CONFERENCE on the technological uses of radiation was held in Sydney recently. More than 100 representatives of the U.K., New Zealand, U.S. and the IAEA, as well as Australians, attended. One of the main topics was the description of the Westminster Carpet irradiation plant for carpet materials.

Argentina

SMALL AMOUNTS of uranium oxide are being supplied to a German concern in exchange for machinery under a barter arrangement. The price for the uranium is believed to be the equivalent of $6 per lb.

Belgian Congo

URANIUM PRODUCTION of the Union Miniere de Haut-Katanga's Shinkolobwe plant amounted to 2,900 tons during 1959, according to the chairman's report. The report also states that the price was lowered to $7 per lb of oxide U_3O_8 contained in the precipitates.

Brazil

A SECOND PLANT for producing pure uranium will be installed at the Atomic Energy Commission in Sao Paulo within the next few months. The plant will have an initial capacity of 250 kg per month.

Canada

AN INTERNATIONAL CONFERENCE for nuclear scientists is to be held at Queen's University, Ontario, from August 29-September 3. It will be sponsored by the International Union of Pure and Applied Physics, the National Research Council of Canada and Atomic Energy of Canada. Attendance is expected to reach 400.

THE BID by Rio Tinto for the remaining contract of Stanrock Uranium Mines has been accepted. The contract will extend the operation of Rio Tinto's Rio Algom Mine by about 6,238,835 lb of uranium oxide. Under the contract Rio Tinto are to pay Stanrock's outstanding first mortgage bonds amounting to about $29 million.

Finland

A CONTRACT has been signed by the Ministry of Commerce and Industry with General Dynamics of the U.S. for the construction of a 100-kW TRIGA research reactor to be built at the Finland Institute of Technology at Otaniemi, near Helsinki. Fuel for the reactor will be supplied by the IAEA.

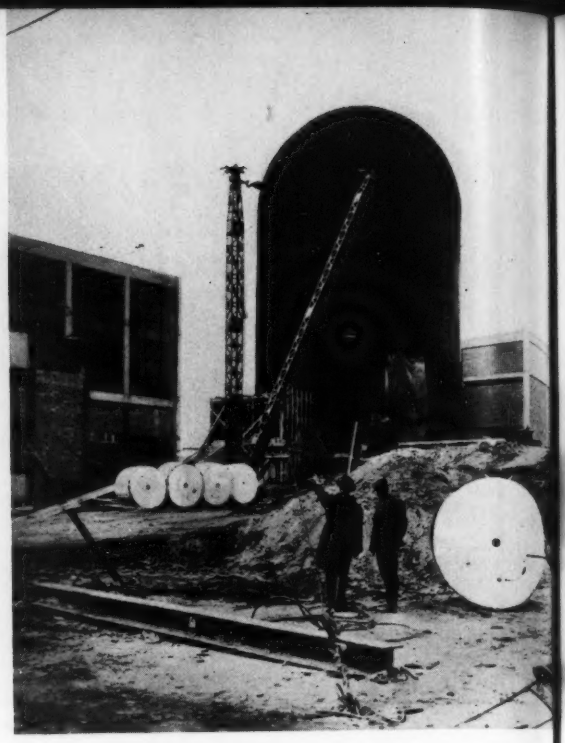
A PAPER-MAKING manufacturer has purchased a beta ray thickness gauge from Tracerlab, U.S. The concern, Oy Control, will install the gauge on a paper-making machine for checking, from edge to edge, the uniformity of thickness of a 20-ft width of paper in process.

West Germany

SMALL POWER REACTORS, of about 15 to 30 MW, will form the main basis of German nuclear investigation over the next few years. It has been announced that this will be in addition to the already proposed 100 MW studies but no definite plans for these larger projects have yet been formulated.

THE LEADING PHYSICIST of the Max Planck Institute of Physics in Munich, Prof. W. Heisenberg, has recently said that nuclear fusion does not appear to be a business proposition owing to the high costs of building a fusion reactor.

A CONTRACT has been awarded General Electric of the U.S. for the fast neutron irradiation of natural graphite by the North Rhine-Westfalia Institute for Reactor Materials. The programme is expected to be completed by the end of the year.



The first West German nuclear power station at Kahl. Built by AEG of Germany and the U.S. concern, General Electric, the 15-MW single-cycle boiling-water reactor is expected to begin operating later this year. The station is being built for RWE and Bayernwerke, two large power utility companies.

India

FINAL CHECKING is being carried out on the NRX-type reactor at Trombay. The reactor is almost complete and expected to go critical this month. The project, a joint Canadian-Indian one, has been built under the Colombo Plan and is expected to become one of the largest radioisotope producers in the world.

IT IS EXPECTED that the fuel fabrication plant at Trombay, with a capacity of 30 tons a year, will manufacture all fuel elements for the NRX and other research reactors.

Israel

THE FIRST FUEL elements for the Nebi Rubin 1-MW pool-type reactor have arrived from the U.S. The fuel is on loan from the U.S. AEC and will be returned when spent. Three cases of neutron sources consisting of several grammes of plutonium mixed with beryllium have also been supplied by the U.S.

Italy

A NUCLEAR SEMINAR, represented by 20 countries, was held at Bellagio recently. The object of the seminar was to discuss the prospects of nuclear energy in Europe for the period 1960-70.

A MISSION of nuclear scientists has recently toured Yugoslavia at the invitation of the Yugoslavia Federal Nuclear Energy Commission. The tour was arranged so that talks could be held on the prospects of co-operation between the two countries in nuclear matters.

Japan

ADVICE on the introduction of a system of management control of nuclear materials is being given by Mr. R. M. Smith of the IAEA. The system will include methods of accounting, stocktaking, measurement and storehousing of nuclear fuels such as natural and enriched uranium, thorium and plutonium.

Philippines

THE SECOND VISIT by a member of the Philippine Atomic Energy Commission to Australia, Mr. P. G. Afable, has taken place. The main purpose of the visit was to study methods of organization and administration of a nuclear centre. The 1-MW pool-type reactor now under construction in the Philippines is expected to begin operating this year.

South Africa

DISCUSSIONS have taken place between the Council for Scientific and Industrial Research and Harwell on the possibility of the large-scale development of a process for removing traces of cæsium.

THE EARNINGS for the export of prescribed materials under the Atomic Energy Act this year have been slightly less than for the same period last year. The first quarter yielded £12.5 million in 1959 as against £12.1 million this year.

Spain

THE FIRST nuclear research reactor to be built by Spain is expected to be installed at the new school for industrial engineers in Barcelona. The reactor is expected to be built for isotope production, but no details have yet been released.

Switzerland

FINAL INSTALLATION and pre-critical tests have caused some delay to the commissioning of the 20-MW DIORIT natural uranium heavy-water research reactor at the Federal Institute of Technology at Wurenlingen and the reactor is now expected to begin operating in August.

Tunisia

FOUR TECHNICIANS of the IAEA recently visited Tunis to study the possibilities of establishing a radioisotope centre for Northern Africa.

U.S.S.R.

ON THE PROPOSAL of the Council of Ministers, the Atomic Energy Administration has been changed to the State Committee for Atomic Energy.

WORK ON THE REACTOR at the 200-MW nuclear power station at Beloyarsk, in the Urals, has begun. The reactor cylinder of the water-cooled, graphite-moderated station is 30 ft high and 29½ ft in diameter. There are 998 fuel channels.

An exact size model of one of the reactors of the icebreaker *Lenin*, on view at the U.S.S.R. Economic Achievements Exhibition at Moscow.

U.S.A.

THE INITIAL ELECTRICAL OUTPUT from Dresden was greater than that of any other operating nuclear plant designed solely for power production, although the station has only been operating at half power. Dresden is a 180 MW boiling water reactor.

A CONTRACT has been awarded Mallinckodt Nuclear for 1,200 kg. of highly enriched uranium metal by the Argonne National Laboratory. The major portion of the material will be used in the fast reactor ZPR-6.

AN OPERATING LICENCE is to be issued by the AEC to the University of Virginia for a pool-type training reactor.

THE NUCLEAR AIRCRAFT CARRIER, *Enterprise*, is expected to be launched in September by the United States Navy. The 85,000-ton ship costing $155 million will be the first nuclear-powered vessel of its kind in the world.

TWO INTERIM land burial sites for the disposal of solid, packaged, radioactive wastes have been established by the AEC. They are located at Oak Ridge and the National Reactor Testing Station, Idaho Falls.

CONSUMERS POWER and AEC have agreed on the basis for a contract for a 50-MW high power density boiling water power plant in Michigan.

AN AGREEMENT has been signed by the AEC with the Tennessee Valley Authority for the operation of the Commission's Experimental Gas-cooled Reactor at Oak Ridge. Under the agreement the Authority will provide some design and construction assistance to the AEC and will train personnel and assist in pre-operation inspection and testing and will operate the reactor until June 30, 1968.

A CONTRACT for architectural and engineering services for a laboratory and reactor buildings for the Ames Laboratory at the Iowa State University of Science and Technology has been awarded by the AEC to Burns and Roe, New York.

AUTHORIZATION has been given General Electric by the AEC to seek proposals for the production of enriched uranium billets in privately owned and operated facilities for the New Production Reactor now under construction at Hanford. The elements will use slightly enriched uranium which will be supplied by the AEC.

GRAPHITE for the Experimental Gas-cooled Reactor at Oak Ridge will be supplied by National Carbon. The contract is worth $704,015.

PRELIMINARY STUDY of a 300 MW boiling water plant with nuclear superheat is being conducted by Atomics International for the AEC.

PROPOSALS have been received by the AEC for the construction and operation of a 50 MW boiling water power plant from the Los Angeles Department of Water and Power, jointly with Pasadena City and from the Western Farmers Electric Co-operative, Oklahoma.

A COMPREHENSIVE STUDY has been started by eight different organizations of the Clinch River downstream from Oak Ridge to determine the dispersion and ultimate fate of radioactive materials released into the river.

THE FIRST graduating class of the International Institute of Nuclear Science and Engineering at the Argonne National Laboratory will comprise 53 scientists and engineers including 49 from 19 different countries.

THE REACTOR SNAP has been operated continuously at design conditions for 1,000 hours at a coolant outlet temperature of 1,200° F. The reactor has now produced more than 100 MW of heat since it began operating in November, 1959.

A CONSTRUCTION PERMIT is to be issued by the AEC to the Georgia Institute of Technology for a heterogeneous heavy-water moderated and cooled tank-type system, fuelled with aluminium-clad, highly enriched aluminium-uranium alloy elements.

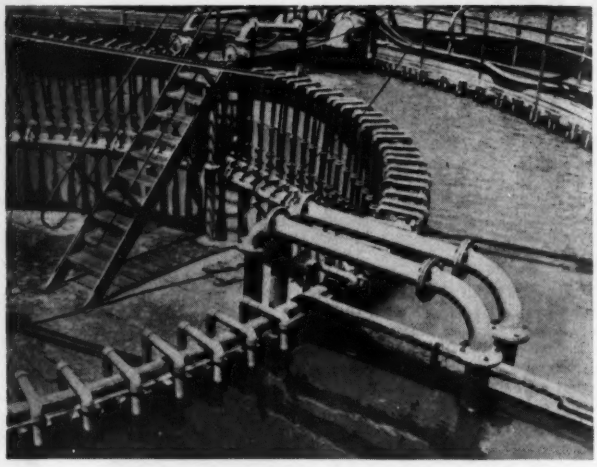
A SYMPOSIUM devoted to the elementary aspects of achieving controllable thermonuclear energy releases is to be sponsored by Oak Ridge and the AEC. It will be held in Gatlinburg from August 22-26.

THE THERMAL CONDUCTIVITY of uranium dioxide powder has been improved by 30% by the addition of tiny fibres of molybdenum, according to a statement by The Martin Company. The mixture was inserted in thin cladding tubes and the entire assembly swaged to increase density to between 84 and 87% of theoretical limits.

A CONTRACT for the construction of support facilities for the mobile low-power reactor facility No. 1 at the National Reactor Testing Station at Idaho Falls has been awarded to Hayes-Henry Construction. The contract is worth $311,035.

Concrete supports for the magnet ring of the zero gradient proton synchrotron at the Argonne National Laboratory. The 5,000-ton ring magnets will rest on the supports.

Industrial Notes



Durapipe fittings in the filter frames of a clarifier at a uranium plant at Western Reefs in South Africa.

Pritchett and Gold and **E.P.S.,** manufacturers of Dagenite accumulators, are to supply eight large direct current batteries and mercury arc and selenium rectifier charging equipment to Hinkley Point. The batteries, which have been ordered by **English Electric,** will be used as standby safeguards capable of supplying a load of 730 kW at a nominal voltage of 440 V for 15 minutes to each of the two reactors.

The **AEA** have awarded a contract to **Avo** for the supply of hot spot monitors. The instruments are used for measuring beta, gamma and X radiation and are equipped with extension rods for remote operation.

Nuclear physics and radiation laboratories will form part of a new **Technical College** to be built at Paisley at a cost of £500,000.

An analogue computer has been supplied by **Miles Electronics** to the Society for Promotion of Nuclear Research in Dusseldorf. Designed by the reactor and computer division of Miles Electronics it will be used for reactor operator training and for testing reactor control gear and computation.

Fibrous Glass Products of Hicksville, N.Y., have developed acoustical insulation made of fibrous glass for nuclear submarines. The insulation is moulded to a cylindrical shape to conform to the inside of submarine hulls.

S. G. Brown, of Watford, the precision instrument engineers, have been sold by the Admiralty to **de Havilland Holdings.**

Construction has begun on new workshops and mechanical laboratories for the **British Scientific Instrument Research Association** at Chislehurst, Kent.

E.M.O. Instrumentation are now the sole agents for the **Barden Corporation** in the U.K. following the acquisition of a substantial interest in E.M.O. by Barden and the winding up of **Quality Bearings.**

Stanton Ironworks announce that they have several new films in their library including one on flexible joints for use with cast-iron pipes and special castings.

The science department of the **British Council** have compiled a catalogue of courses in the U.K. in pure and applied sciences concerned with the use and development of nuclear energy.

Vickers and Herr Hans J. Zimmer of Frankfurt have formed a joint enterprise, **Hans J. Zimmer Aktiengesellschaft fur Industrieanlagenbau,** for plant design, engineering and construction and for the chemical and man-made fibre industries.

Final attendance figure at the **Instruments, Electronics and Automation Exhibition** was 75,276 including 4,015 from overseas.

The **U.K. AEA** exhibited at the **7th Rassegna Internazionale Elettronica, Nucleare e Teleradiocinematografica** exhibition in Rome during June.

The electrical engineering department of the **Loughborough College of Technology** has arranged a short course on control engineering theory and practice during July.

Aveley Electric are now the agents for all products of the **Allen B. du Mont Laboratories** of the U.S. in the U.K.

Ekco announce the completion of a new 26,000-sq-ft building at their headquarters near Southend.

International Rectifier (Great Britain), a company formed by the **Metal Industries Group** and **International Rectifier Corporation,** of Los Angeles, recently opened their new factory at Oxted where they are manufacturing silicon diodes, and selenium rectifiers.

Full particulars of the proposed merger of **Henry Simon (Holdings)** and **Simon-Carves** have now been published.

Firth Cleveland have acquired **J. J. Habershon and Sons** from the **Iron and Steel Holding and Realisation Agency** for £700,000.

Chloride Electrical Storage have opened new battery research laboratories at Clifton, Swinton, near Manchester.

Considerable extensions have been made to the Glasgow branch of **Wolf Electric Tools.**

The symposium on nuclear reactor containment buildings and pressure vessels held at the **Royal College of Science and Technology** in Glasgow during May was attended by 250 visitors including 100 from overseas.

A new **British Standard** (B.S. 1651:1960) for industrial protective gloves has been prepared.

The faculty of applied science of the **University of Nottingham** are holding a residential course on measurement for automatic control from September 12-16.

Details of the **Queen Mary College** post-graduate course in nuclear engineering for 1960-61 are now available.

Ultra Electric (Holdings) celebrated their 25th anniversary on June 14.

More than 130 lectures will be delivered at the **Fifth International Instruments and Measurements Conference** at Stockholm, September 13-16.

General Electric have recently installed and commissioned a 3-roll cold plate bending machine at their Erith engineering works. The machine will enable the company to bend mild steel plate up to 4¾ in. thick.

Lancashire Dynamo have produced a film illustrating how automatic control can help industry towards greater production.

The new **AEI** research laboratories at Harlow, Essex, were opened by Lord Chandos, chairman of the company, on May 17.

BICC have announced a unilateral selling scheme for rubber and thermoplastic insulated cables.

CEGB contracts for power stations, transmission lines and transforming stations for the past two months amount to £7,127,000.

New and recent changes of addresses are:
Edwards High Vacuum German address is Frankfurt Main-Niederrad, Hahnstrasse 34.

The Nottingham office of **Cambridge Instruments** is now Century Insurance Building, Milton Street, Nottingham. Tel.: 42612.

Graviners' industrial temperature control division are now at 10 Church Street, Staines. Tel.: Staines 51217.

L. G. Mouchel and Partners are now at Southbank House, Black Prince Road, London, S.E.11. Tel.: Reliance 7691.

The Manchester depot of **Pritchett and Gold** and **E.P.S.** is now 17 Rainforth Street, Longsight. Tel.: Rusholme 1551.

An optical design group is to be established at the **Imperial College of Science and Technology.**

Processes and Equipment

For further information on any item please enter the relevant number on the Reader Service Card enclosed with this issue and forward the card to the address given.

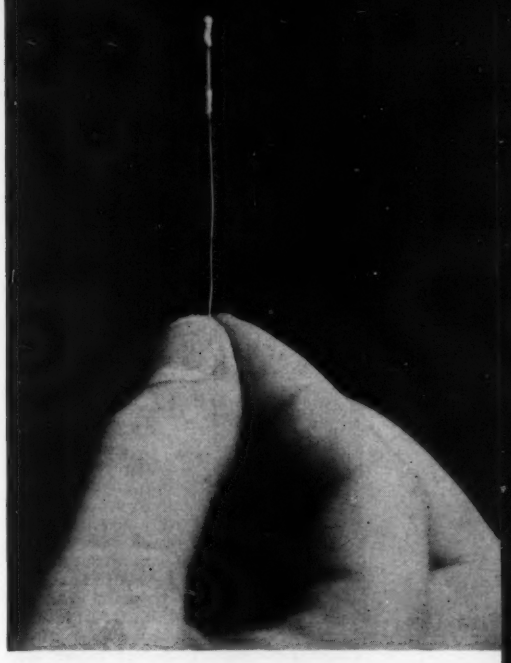
Cadmium Sulphide Gamma-ray Detectors

Improvements in the purity of cadmium sulphide crystals have enabled them to be applied to gamma-ray detection, and development is being carried on at the Harlow laboratories of A.E.I. (Woolwich), Ltd., on two main types.

The "standard" type, horizontally mounted on a header under a glass dome, has a diameter of ¼ in. and a height, excluding the connecting wires, of about the same. Exposed to Co-60 radiation of 1 r/min with a 100V battery it gives a current of about 1 μA and a decay time of 8 sec to 1/10 of true gamma current.

The "intracavitary" type (illustrated), primarily intended for medical work, has the crystal mounted axially in a thin-walled glass tube, for probe use, one terminal being a Dumet wire sealed into the glass, and the other a silver cap. The overall length, excluding wire, is about 14 mm, and the maximum diameter 1.7 mm. Sensitivities fall into one of two groups. In Group 1, the minimum total gamma current is 0.2 μA and the decay time to 1/10th is 8 sec maximum. In Group 2, the minimum current is 0.03 μA, and the maximum decay time is 2 sec.

Both standard and intracavitary types of cell have a linear response to voltage, the maximum allowable being 100V (peak) a.c. or d.c.



A.E.I. intracavitary type cadmium sulphide cell.

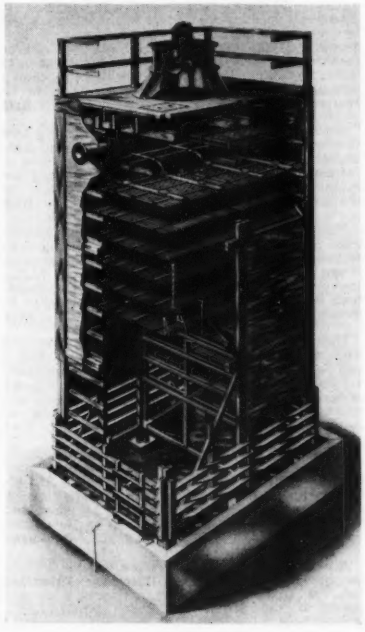
(Associated Electrical Industries, Ltd., 155 Charing Cross Road, London, W.C.2.)

1321

New Cooling Tower

A new Foster Wheeler cooling tower, the Type D, has been designed. Of the induced-draught pattern, it is constructed of treated timber in standard units, for simple bolted erection by unskilled labour. With cross-sections ranging from 6 ft-16 ft square, it can be supplied suitable for 50-1,500 gal/min. Good features of the design are the drift eliminators to prevent entrained droplets being carried to atmosphere by the discharge stream, thus reducing water losses, and the ability to set the anti-splash louvres at the base of the tower in either diagonal formation, for normal running, or in vertical formation to retard icing in winter conditions.

Foster Wheeler "D" type cooling tower.



(Foster Wheeler, Ltd., Foster Wheeler House, 3 Ixworth Place, London, S.W.3.)

1322

Expansion Bellows

A recent arrival in the bellows field is the Vokes Group. Standard material is 18/8 cold-rolled stainless steel, but Nimonic 75 can be used for temperatures above 750°C, and monel, Inconel, or titanium for abnormally corrosive situations. Tubes are manufactured with a longitudinal butt weld, under carefully controlled conditions; convolutions are formed on machinery designed within the group; there are no circumferential welds.

Typical Vokes' expansion bellows.

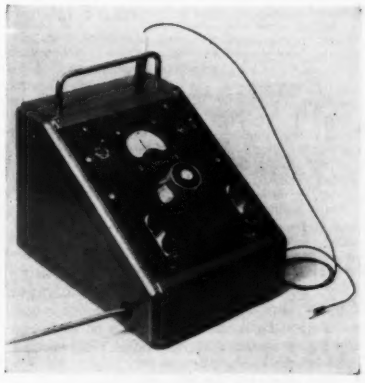
Diameters of 120 in. or over are possible; rectangular and other shapes can be supplied if required. All types of restraint, such as hinged, gymbal, tied, articulated, and any type of coupling arrangement can be supplied.

(Vokes Genspring, Ltd., Henley Park, Guildford, Surrey.)

1323

Plotter for Electric Fields

The technique of an electrolytic tank for solving electric or magnetic field problems is reasonably well known. The new Servomex field plotter FP92 gives, in effect, a two-dimensional electrolytic tank technique. A special resistive paper has the electrodes drawn on it in conducting ink and, upon a potential being applied, equipotential lines may be traced by means of the plotter with a probe electrode in the form of a pencil. It provides a simple and economical method of solving many problems in electromagnetism, mechanics, heat transfer, etc., to which the resistance analogue technique could normally be applied, at a cost well within the means of schools and colleges.



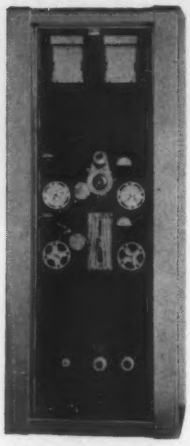
The Servomex field plotter.

(Servomex Controls, Ltd., Crowborough, Sussex.)

1324

Air Monitor

Of interesting design is a German-built unit for the continuous monitoring of airborne activity in laboratories, or in the vicinity of reactor sites or processing plants.



Frieseke and Hoepfner air monitor.

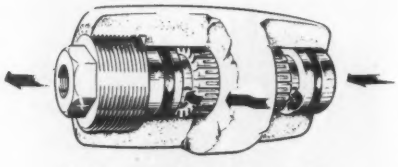
By means of a two-stage blower and a vacuum pump, a constant, regulated flow of air passes through a filter in the form of a tape driven by a synchronous motor, the tape being monitored by a scintillation counter equipment and recorded. At this time, the prevailing activity is normally short-life, due to radon, etc., occurring naturally. The tape moves on, via a system of reversing rollers, and is later monitored by a second counter and recorder equipment, to determine long-life activity. The minimum detectable concentration at 5 counts/min above background, and a tape speed of 50 mm/h, is approximately 5×10^{-13} c/m³.

(Frieseke and Hoepfner G.m.b.H., Erlangen-Bruck, Germany.)

1325

Adjustable Filters

On the basis that regulated filtration is as necessary as any other form of control, what is claimed to be the first adjustable filter has been placed on the market. The filter element consists of a plug with a slight taper, having longitudinal grooves extending part of the length, and communicating alternately with one or other of the ends. This is contained within a similarly tapered housing, the relative positions of plug and housing being adjustable, so that the clearance between them can be varied. Since communication between the two sets of slots can only be obtained via this radial clearance, a slight lengthwise movement will vary the size of the particles which can pass, and by rotating the housing on a screw thread, very fine adjustment (0-5μ) is possible.



I.V. Pressure Controllers' adjustable filter.

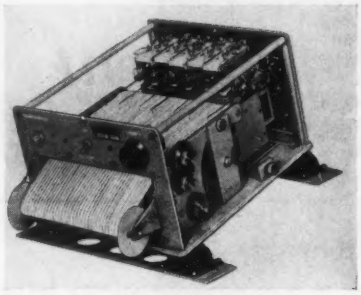
The range at present standardized is from ¼-in. to 1-in. pipe, in steps of ¼ in. Each pipe size has three models, for 0-5, 5-15, and 15-25μ particle size; the working pressure is at present 4,500 p.s.i., but higher pressures are under development.

(I.V. Pressure Controllers, Ltd., North Feltham Trading Estate, Spur Road, Feltham, Middlesex.)

1326

Direct-writing Recorders

ABEM chart recorders are now available with as many as 12 channels together with two event markers for time or incident recording. The recording heads are centre-tapped moving-coil galvanometers for d.c. signals or a.c. up to 1.5 c/s. A wax-coated chart gives a bright red trace from the pens, which are heated, the heating being simultaneously adjustable on all pens to alter the thickness of the trace. Illustrated is a five-channel instrument developed for airborne survey work. Multi-trace photographic-recording oscillographs are also made.



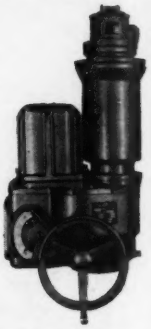
ABEM five-pen recorder.

(AB Elektrisk Malmletning, Danderydsgatan 11, Stockholm, Sweden.)

1327

Valve Actuators

Two new ranges of electrical valve actuators are announced by the Jones Tate Division of Dewrance and Co., Ltd., for spur or worm drive. Main features of the new designs are increased torque and reduced dimensions; there are many other good points. In addition to the normal limit switch arrangement, torque switch control is provided giving protection against damage due to overtravel, while a centrifugal clutch ensures that the motor is under no-load conditions, not only during starting, but in the event of instantaneous reversal during travel. There is a "notching" arrangement for dealing with sticking which might occur during travel; if the valve sticks, the drive is mechanically disconnected and re-applied in a series of hammer-blows, limited to twice full-load torque. Engagement of the handwheel is automatic; there is no external mechanism to engage for hand operation and, even when in use, it is automatically disengaged when power is applied, thus eliminating the risk of accidents.



Jones Tate (Dewrance) flameproof/weatherproof valve actuator.

Ten standard ratings are available, giving valve spindle torques from 30 lb-ft to 3,500 lb-ft at 24 r.p.m., and weatherproof or weatherproof-flameproof finish can be supplied.

(Jones Tate and Co., Ltd., 165 Great Dover Street, London, S.E.1.)

1328

BRIEFLY . . .

Special adaptations of standard globe valves for low-temperature work are announced by **Hunt and Mitton, Ltd.,** Oozells Street North, Birmingham, 1. An extended spindle is fitted with a bronze gland of finned construction to absorb atmospheric heat, and maintain the gland at normal temperatures. Sizes available are ½ in.-3 in. **B133**

Rockweld, Ltd., Commerce Way, Croydon, Surrey, are introducing the Circomatic seam welding machine. Mainly intended for field welding of circumferential seams in large tanks, it welds both sides of the seam simultaneously, using flux-cored wire in a CO_2 protective atmosphere, and is said to be ten times faster than normal methods. **B134**

A multi-way switchgear unit has been developed by **N.G.N. Electrical, Ltd.,** Avenue Parade, Accrington, for use with the PCDR.2 control unit for Pirani gauge heads in a vacuum system, so that the facilities of the control unit (i.e., pre-heat, out-gas and leak detection) are available on all gauge heads. **B135**

Brooks Rotameter Co., P.O. Box 432, Lansdale, Pennsylvania, announce a new pneumatic signal converter model 850 which will enable the transmitted signals from square root flow meters to be converted into linear signals and, in general, to convert any pneumatic signal into a corresponding output signal of different type **B136**

The English Electric Co., Ltd., Marconi House, Strand, London, W.C.2, have developed a new electrode known as THERMEES which is handled like a normal welding electrode but is intended to apply a rapid and concentrated heat to metal before welding, bending, or straightening. The temperature rise of the metal can be regulated by the rate of travel and the number of passes, and any residual scale or oxide can easily be brushed off, leaving a clean surface. **B137**

New electron beam melting plant is announced by **Fleischmann (London), Ltd.,** Chancery House, Chancery Lane, London, W.C.2, who are the U.K. agents of W.C. Heraeus G.m.b.H. (Hanau, Western Germany). New techniques have eliminated the glow discharges during melting which have hitherto proved a handicap. In addition, since the melt material does not act as an accelerating electrode it is unnecessary for it to be metallic and non-conductors, ceramics, and semi-conductors may be used. **B138**

Information regarding machinable refractories has been received from **W. and C. Spicer, Ltd.,** The Grange, Kingham, Oxfordshire. In addition to Zirconite, their machinable form of Zircon which has been established for some time, they have recently added machinable alumina and silicon carbide. All three are available in bars, slabs and billets and require no further firing after machining although Zirconite can be flame-hardened if required. **B139**

Sel-lok, a new self-locking spring pin has been developed by **Unbrako Socket Screw Co., Ltd.,** Burnaby Road, Coventry. Requiring no tapping or reaming, Sel-loks can replace taper pins and are made in sizes of 1/16 in. to ½ in., suitable for shafts of 3/16 in. to 1½ in. diameter. **B140**

Philips Cryogenic equipment has been considerably improved in performance, it is stated by **Research and Control Instruments, Ltd.,** Instrument House, 207 Kings Cross Road, London, W.C.1. Improvements to the refrigerating machine enable both the liquid air and liquid nitrogen plants to be increased in capacity by 50%. **B141**

Durusol, a stoving coating that can be thinned with water, is being produced by **Arthur Holden and Sons, Ltd.,** Bordesley Green Road, Birmingham, 9. This will eliminate oven-drying before painting or spraying, and will enable painting equipment and booths to be washed down without the use of solvents. **B142**

Intereng. 59 Birkbeck Road, Newbury Park, Ilford, Essex, are marketing a battery-operated effluent sampler. Weighing less than 30 lb. (including batteries) its pumping rate is such that it accumulates a 2 gallon sample in 24 hours and may be operated for a period of up to 3-4 months on one set of batteries. **B143**

A new general-purpose valve test set, the VT. 10 has been developed by **APT Electronic Industries, Ltd.,** of Byfleet, Surrey. It is intended to test valves to the British CV and American MIL specifications. **B144**

Flexible Hose

Originally conceived as a high-quality hose for domestic vacuum cleaners, Vacuflex has now been developed in a wide range of types and materials for air ducting, etc. Present available sizes are from 1-4 in. bore; larger

Illustrating the pliability of Vacuflex hose.

sizes, up to 8 in., will be available shortly. Rigidex, a semi-flexible pipe, is another development. Materials used for various grades and duties include high-density polythene, p.v.c., polypropylene, nylon, etc., and fabric reinforcement of cotton, glass fibre, Terylene or wire mesh can be provided. Lightness, and high mechanical strength, with the ability to produce in long lengths, are some of the special features; the ability of certain grades to resist boiling water and organic solvents are amongst other desirable properties.

(Recon (Pipelines), Ltd., Sheerwater, Woking, Surrey.)

1329

Direct-reading Oscilloscope

Digital read-out is an attractive feature of the new type 425 oscilloscope manufactured by the Allen B. Du Mont Laboratories (New Jersey) and marketed in the U.K. by Leland Instruments, Ltd. Built on the modular system, in five easily replaceable units, it is easily maintained, and allows of extension of scope and performance by means of plug-in units.

Du Mont digital read-out oscilloscope.

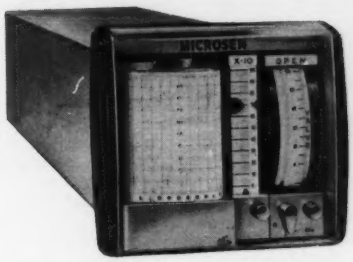
Suitable for use up to 60 Mc/s, the tube has a display area of 10 × 5 cm. The numerical read-out available makes it possible to use the instrument in production control processes, by unskilled operators; the read-out may be connected directly to punched card equipment, if required.

(Leland Instruments, Ltd., 22 Millbank, Westminster, London, S.W.1.)

1330

Process Control

Manufactured under licence from Robertshaw-Fulton Controls, of California, the Dewrance Microsen control system can be applied to the remote control of processes of any size and type. Utilizing d.c. signals between transmitters and receivers, the system is unaffected by induced a.c. in the control cables, or by varying line resistance (up to a maximum of 3,000 ohms). The miniature chart recorder-controller (illustrated) operating on 1-5 mA d.c., is suitable



Dewrance Microsen recorder-controller.

for proportional + integral + derivative control with an accuracy of ± ½% of set-point; the recording pen is servo-operated.

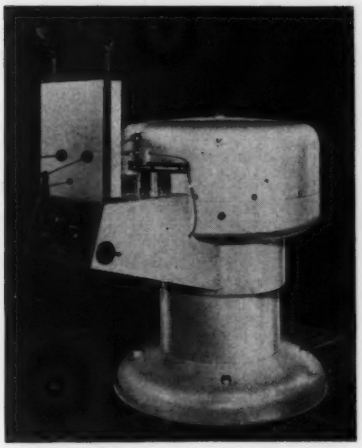
Other devices in the range include indicating controllers, with vertical or circular scales; indicators; recorders; transmitting potentiometers for thermocouple resistance thermometer or strain gauge inputs; and transmitters of various types for levels, pressures, etc., and output transducers for compressed-air operation.

(Dewrance and Co., Ltd., Great Dover Street, London, S.E.1.)

1331

Isotope Storage Unit

Primarily intended for medical work, in the storage of needles and applicators, the Pantasafe I provides storage space and safe



The Pantasafe I isotope storage unit.

handling facilities for a total of 2g of radium, or its equivalent. A pedestal-mounted circular steel safe contains an annular motor-driven turntable on which are placed the sources, in segmental lead-shielded carriers. Forty such carriers may be used, each instantly accessible by rotation of the turntable to bring the appropriate carrier into position to enable it to be slid out on to the manipulation table. Mechanical and electrical interlocks prevent mal-operation, and a locked shielded door prevents unauthorized access. Additional shielding may be added in the form of steel-framed lead brick front and side walls.

(Pantatron, Ltd., 5a Prince's Street, Hanover Square, London, W.1.)

1332

CATALOGUES

A directory of engineering manufacturers has been received from the **Office of Industrial Information.** Containing some 1,200 pages, it lists selected manufacturers and their products in English, French, Spanish, Italian, German and Russian. (Bureau de Documentation Industrielle, 4, Tour de l'Ile, Geneva.)

" Industry needs Regalox " is a title of a booklet received from **Royal Worcester Industrial Ceramics, Ltd.,** describing the physical properties of Regalox high-alumina ceramics. (Tonyrefail, Glamorgan.)

Constructors John Brown, Ltd., have issued a booklet on their electronically controlled, multi-component Blending System. (Seagrave Road, London, S.W.6.)

Keith Blackman, Ltd., have issued a new edition of " Heavy Fan Engineering." (Mill Mead Road, London, N.17.)

Lists showing the ranges of silicon diodes and selenium rectifier stacks have been received from **International Rectifier Co. (Gt. Britain) Ltd.** (Hurst Green, Oxted, Surrey.)

W. G. Pye and Co., Ltd., announce a new scientific instrument catalogue (" N ") which supersedes previous issues. A number of important new developments are described. (Granta Works, Cambridge.)

Turners Brothers Asbestos Co., Ltd., have issued a publication on their " Poly-V " drives. This type of belt combines the characteristics of flat and V belts. Complete particulars and design tables for light and heavy drives are included.

Another Turner catalogue covers a wide range of rubber conveyor belting. (Rochdale.)

"A Swedish Metal Industry " is the title of a book issued by **AB Svenska Metallverken** showing in pictorial form a number of their establishments and products. (Stockholm, Sweden.)

List. No. 2304 from **Sturtevant Engineering Co., Ltd.,** supersedes publication 2303, and briefly describes the entire range of Sturtevant products and services. (Southern House, Cannon St., London, E.C.4.)

High-precision needle bearings are the subject of a booklet in English, German and French, describing " Nadella " bearings, received from the U.K. distributors **Insley Industrial Supply Co., Ltd.** (21/22 Poland Street, London, W.1.)

Quartz fibre dosimeters, chargers, Roentgen meters, and isotope analysers are described in a catalogue received from **The Landsverk Electrometer Company.** (641 Sonora Avenue, Glendale 1, California.)

Evershed and Vignoles, Ltd., have issued publication No. 327, describing the new series 3 " Megger " insulation and continuity tester which incorporates a number of new features. (Acton Lane Works, Chiswick, London, W.4.)

Nevelin silicon rectifiers are described in a new list, N 120, received from **Lancashire Dynamo Nevelin, Ltd.** (Hurst Green, Oxted, Surrey.)

Claude Lyons, Ltd., have issued a leaflet describing " Variac " d.c. motor speed controls. (Valley Works, Ware Road, Hoddesdon, Herts.)

Wray (Optical Works), Ltd., have issued a leaflet describing various types of optical aids, including magnifiers and microfilm readers. (Bromley, Kent.)

Duplex filters for oil and chemical work are described in a new catalogue received from **Plenty and Son, Ltd.** Sizes listed are suitable for pipes from ¼ in. to 30 in. diameter. (Eagle Iron Works, Newbury, Berks.)

" Foliac Colloidal Graphite " is the title of a folder from the **Morgan Crucible Co., Ltd.** (Battersea Church Road, London, S.W.11.)

Various types of ferrous alloy castings (s.g. iron, NOduMAG, etc.) are covered by a publication received from **Ferranti, Ltd.** (Hollinwood, Lancs.)

A folder from the Paints Division of **Evode, Ltd.,** describes " Evoflor " heavy-duty floor paint, for concrete, asphalt, wood, or linoleum. (Common Road, Stafford.)

" Duodesk " combined writing desk-drafting units, and Simplon-Nestler drafting machines with hydraulic lifting stands are described in leaflets received from **Dargue Brothers, Ltd.** (New Simplon Works, Halifax, Yorkshire.)

The Cary-White Model 90 infra-red spectrophotometer, the Model 39 multi-range recorder, and the Model 36 vibrating reed amplifier are described in leaflets from the **Applied Physics Corporation.** (2724 South Peck Road, Monrovia, California.)

" Middlesex " prefabricated buildings are described in a leaflet issued by **J. E. Lesser and Sons, Ltd.** (Green Lane, Hounslow, Middlesex.)

Patents Reviewed

These abstracts have been made from British Patent Specifications, complete copies of which can be obtained from the Patent Office, 25 Southampton Street, London, W.C.2, at 3s. 6d. each (including postage).

B.P. 821,861. Heat transfer systems in nuclear reactor fuel elements. W. B. Hall. To: U.K. Atomic Energy Authority.

A fuel element axially arranged in a circular channel is provided with transverse fins; these being divided into an even number of segments (greater than two), which are alternately deflected against, and with, the direction of the fluid flow along the channel. The fins may be radially cut to permit the deflection.

B.P. 821,915. Shields for nuclear reactors. I. J. Lockyer. To: Morgan Crucible Co., Ltd. (add. to 797,692).

A shield for the simultaneous moderation and absorption of neutrons is made of a consolidated mass of amorphous carbon, or mixture of amorphous carbon and graphite, and includes a carbonized binder and a boron compound (anhydrous borax). As the amorphous form of carbon is more resistant than graphite to dimensional changes induced by neutron bombardment, this should constitute a substantial part.

B.P. 822,356. Two-zone breeder nuclear reactor. R. G. Tongue. To: U.K. Atomic Energy Authority.

The reactor is characterized by having a blanket liquid of a lower pressure than its core liquid, at a given temperature. Reduced pressure in the blanket vessel simplifies its mechanical construction. Higher temperature in the vessel increases thermal efficiency.

B.P. 822,415. Nuclear reactors. R. J. Smith. To: General Electric Co., Ltd.

The temperature within the core is kept constant over a range of power levels by a combination of two reference signals in a predetermined relationship with one another. These signals influence the neutron flux in the core and also the flow of cooling medium in a first and a second closed loop control circuit, the one for the neutron flux and the other for the cooling medium.

B.P. 822,430. Steam generators. A. Huet. (France.)

Vaporizer units having some characteristics of both water-tube and fire-tube boilers. Around a closed cylindrical water and steam vessel are disposed water-tubes the ends of which are connected to the vessel near its ends. Inside the vessel are tubes traversed by the hot fluid from the reactor. The external water tubes are connected to secondary headers radiating around the cylindrical vessel. All the welded joints can be made on the outside for easy inspection and repair.

B.P. 822,629. Fuel elements for nuclear reactors. To: Physikalische Studiengessellschaft Düsseldorf G.m.b.H. (Germany).

In a reactor operating with plutonium as fuel, the elements may contain a fuel compound of plutonium with a metal or metalloid of a low neutron absorption cross-section, e.g., they may contain or consist of plutonium carbides (oxides, nitrides, silicides) shaped in finely divided form and sintered. The pore volume may range from 10 to 50%. Such reactors can operate with gaseous exchange media at 800 to 1000°C, with liquid coolants at up to 500°C.

B.P. 822,560. Ionization chambers. To: General Electric Co. (U.S.A.)

The chamber contains an electron-emissive cathode and a co-operating anode. A potential difference can be applied between anode and cathode to cause space-charge current flow in the absence of radiation, but a much larger current flows in the presence of ionizing radiation.

B.P. 822,788. Piles of moderator and/or reflector elements for nuclear reactors. To: Commissariat à l'Energie Atomique (France).

The graphite moderator in nuclear reactors is usually constituted of a multiplicity of blocks, arranged parallel or crossed one above the other. Although crossed layers give good stability, high differential expansions are created, while the anisotropic properties of the material cause the blocks to creep. Superimposed layers of parallel blocks are not stable, and require highly complicated mechanisms which, owing to the high friction between graphite blocks, are not safe. In order to overcome these difficulties, the pile is built up of a number of vertical columns with side walls close to, but not touching one another. Each column consists of a number of horizontal layers resting on one another and each layer consists of parallel blocks slightly spaced from one another, the longitudinal direction of the blocks of one layer being at right angles to that of the next layer. Isostatic (not stress-producing) connections maintain the position of the blocks of a layer with respect to at least one of the blocks of the layer underneath, to prevent deformation due to Wigner and thermal effects.

B.P. 823,110. Electromagnetic interaction pumps. L. R. Blake, British Thomson-Houston Co., Ltd.

The pump has a moving magnet system and is suitable for high-pressure applications. A rotatable magnet is arranged within a helical duct of rectangular cross-section. The rotation of the radial field across the duct produces a circumferential movement of the liquid metal.

B.P. 823,672. Method and apparatus for nuclear reactor safety control. To: U.S. Atomic Energy Commission (U.S.A.).

A sudden increase in the neutron flux causes a rise in temperature in the safety device which consists of a tube in the reactor core containing neutron-absorbing material (poison) and a pressurized gas. The rise in temperature causes a fusible plug to melt and the gas pressure then expels the poison thus rapidly increasing its surface area.

B.P. 824,034. Fuel elements for nuclear reactors. To: Deutsche Gold- und Silber-Scheideanstalt (Germany).

When metallic fuel must be bonded to the can, the use of fluxes should be avoided. Furthermore the interlayers should not accelerate the diffusion process between core and can to such an extent that the purpose of the casing would be defeated at higher temperatures with increased diffusion velocity. Sodium and sodium potassium alloys are not satisfactory. It has been found that an interlayer of an alloy containing zinc and the core material (e.g., uranium-zinc alloy) prevents the diffusion of the uranium into the can. A solder layer may be introduced between the zinc alloy and the can, e.g., a layer containing lead, bismuth or tin.

B.P. 824,377. Nuclear reactor arrangements. H. W. Davidson, J. F. Strachau. To: General Electric Co., Ltd.

In gas-cooled reactors, high mass flow is obtainable, without high pressures or excessive blower power, by small particles (10-50μ), having a high heat capacity per unit volume, kept in suspension in the gas. Particles may conveniently be of the moderator material, e.g., graphite in CO_2.

B.P. 824,829. Nuclear reactors. To: Sulzer Frères S.A. (Switzerland).

If pressurized water is used as the heat carrier the pressure necessary to prevent steam from forming in the reactor may amount to 100 kg/cm². This also applies to other liquids of low boiling-point. Large, thick-walled, pressure vessels are therefore necessary. When subdividing large vessels, to obtain thinner walls, a disadvantage arises from the increased mass ratio between fissile material and vessel and other jackets through which the neutron stream passes. A solution of the problem has been found in building up the reactor from bodies of metallic fissile material in which are embedded tubes through which the cooling water flows. The only reactor cavities subject to high pressure are then the bores of the cooling tubes. Little material is required as the expanding tubes are held together by the surrounding fissile material. Furthermore only a relatively small proportion of the neutron stream passes through the walls of the tubes. The tubes may be shrunk into the cavities of the fissile material i.e., cooled during the embedding procedure so that the fissile material will firmly enclose the tubes when the tubes regain the temperature of the surrounding material. Or the fissile material may be cast or sintered on to the cooling tubes. Preferred materials for the cooling tubes are zirconium and stainless steel.

B.P. 825,196. Mechanism for transmitting motion through a physical barrier. To: Atomic Energy of Canada, Ltd. (Canada).

The difficulty of designing a fluid-tight seal permitting a shaft to pass through, to rotate or slide without any fluid leaking through the carrier, regardless of temperature and pressure, has been overcome by provision of a second fluid (hydrocarbon or silicone oil) maintained in a closed chamber at the same pressure as the principal fluid. from which it is separated by a common wall This chamber contains also the motive power for the mechanism (control-rod movement). Since the electrical equipment is immersed in the fluid with the conductors sealed into a wall, simple manufacture is possible. The intermediate fluid may further serve for leak detection.